MILE POST 7 WEST RIDGE RAILROAD RELOCATION, DAM EXTENSIONS, AND STREAM MITIGATION PROJECT ENVIRONMENTAL ASSESSMENT WORKSHEET (EAW)

RECORD OF DECISION – FINDING OF FACT 28.t
2009 DAM STABILITY REPORT

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Stability Evaluation of Dams 1, 2, and 5

Milepost 7 Tailings Basin
Silver Bay, Minnesota

Prepared for
Northshore Mining Company
Silver Bay, Minnesota

July 2009

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BARR

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

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Circular Failure
Block Failure
Proposed Geometry El.1,245 feet
Circular Failure
Block Failure
Proposed Geometry El.1,315 feet
Circular Failure
Block Failure

Dam 5
Proposed Geometry El.1,230 feet

Circular Failure
Block Failure
Proposed Geometry El.1,245 feet
Circular Failure
Block Failure
Proposed Geometry El.1,315 feet
Circular Failure
Block Failure

Certification:

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly licensed professional engineer under the laws of the State of Minnesota.

Aaron T. Grosser

Aaron T. Grosser, P.E.

Registration No. 25997 Date: 7/31/09

Executive Summary

This report presents the results of a seepage and stability evaluation of the tailings dams at the Northshore Mining Company (NSM) Milepost 7 Tailings Facility near Silver Bay, Minnesota. The tailings dams are required to contain and store the iron ore plant aggregate, belt filter tailings, and fine tailings produced during the ore beneficiation process and provide a reliable source of process water. The tailings basin impounds both process water and tailings using the offset upstream dam construction methods. As a result of on-going dam design and evaluation, in 2003 a change to the dam design was proposed and implemented. The new design consists of an offset upstream dam where the seepage cutoff was relocated approximately 800 feet upstream of the previous glacial till cutoff. As part of the offset upstream construction, the new dam will have flatter 6H:1V downstream slopes. At Dams 1 and 2 a seepage collection trench was also incorporated into the design to collect seepage water and direct it to the seepage collection ponds downstream of Dams 1 and 2.

The evaluation performed on Dams 1, 2, and 5 consisted of seepage analysis and slope stability analyses for the existing dam configuration; for the next two dam raises to elevations 1,230 feet and 1,245 feet; and for the ultimate dam elevation at 1,315 feet. The existing condition was used to calibrate the seepage models with the observed seepage and pore pressures measured from instrumentation and from the values provided in the geotechnical evaluation. The seepage models for the proposed conditions were used to predict the groundwater flow and pore-water pressures for use in the slope stability models.

The analyses presented in this report represent a conservative approach to the evaluation of the dam seepage and stability as measured by the use of the shear strengths used, the high pond level incorporated into the model, the fact that relief wells were not incorporated into the models, and the modeled total heads exceeded the measured total heads.

The slope stability analyses included an assessment of the sensitivity of the factors of safety for differing soil strengths for the lacustrine clay and the fine tailings. The fine tailings strength was varied between two conditions; the yield strength and the liquefied strength. The analyses of the foundation for the dams were varied between two failure modes; the block failure surface and circular failure surface through the lacustrine clay or lacustrine clay and glacial till interface. The strength of the lacustrine clay varied between the average value and the lower-bound values, as presented in Barr (2009), for each failure mode.

The results of the analyses show the dams are stable for the next two raises to elevation 1,230 feet and 1,245 feet. The dams are also stable for the ultimate dam configuration at elevation 1,315 feet. Since many changes may take place during the next 60 years of operation, the results for the ultimate dam configuration are considered preliminary but provide a guide for long range planning. The resistance to uplift at the toe of Dam 1 is considered marginal based on the existing instrumentation data and proposed model conditions. The instrumentation at the toe of the dam and relief wells should be reviewed and validated prior to the next dam raise. The resistance to uplift at Dam 2 is considered adequate. Using the prescribed construction methods at Dam 5, the resistance to uplift will also be acceptable. This report presents recommendations for further evaluation of the instrumentation along the toe of the slope and the relief wells that are critical components in the evaluation of the uplift pressures at each of the dams.

1.0 Introduction

Northshore Mining Company (NSM) operates the Milepost 7 tailings basin near Silver Bay, Minnesota, for the storage of tailings, a byproduct of the mineral beneficiation process. The basin has been operated intermittently from its construction in the 1970s to the present, using approximately the same construction methodology as proposed in the design documents. In 2003 Barr Engineering Company (Barr) proposed to alter the design cross section of Dam 1 and Dam 2 for future construction. To comply with regulations for safely storing tailings, NSM and Barr developed an investigation and engineering analysis program for the tailings basin dams in support of the changes proposed for Dam 1 and Dam 2. The geotechnical evaluation report summarized geotechnical parameters recommended for use in design and construction of future dam raises. The conclusions are presented in a report in 2009 titled, *Geotechnical Evaluation Report for Dam Construction and Foundation Materials.*

Previous dam stability analyses were performed by Klohn Leonoff (Klohn) of Richmond, British Columbia, Canada and Sitka Corp. (Sitka) of Kirkland, Washington, to evaluate the stability of the dams during the initial design phase and later operations. The analyses centered on the original design cross section and layout of the dams. Barr proposed to alter the design cross section of Dam 1 and Dam 2 for future construction. This was due to the potential lack of plant aggregate necessary to complete the required construction projects at the tailings basin in 2003 and possibly in the future. The design for Dams 1 and 2 was changed to the offset upstream method as shown on Figures 1.1 and 1.2. In this method a filter berm is constructed approximately 800 feet upstream of a starter dam and fine tailings are discharged onto a beach. The area downstream of the filter berm is constructed with plant aggregate. The proposed dam slope above the seepage collection ditch is 6H:1V, ending at a crest elevation of 1,315 feet. The Dam 5 design remained unchanged with a glacial till core until 2004, when Dam 5A and Dam 5B were connected in one dam alignment.

The tailings pond water level rises about 1.5 feet per year and the minimum recommended freeboard is 8 feet. The water treatment plant allows some control of the water level within the tailings pond. The water level rise sets the pace of construction of the dams to meet freeboard requirements.

This report addresses the seepage and stability of Dams 1, 2, and 5 using the revised dam cross section and updated geotechnical information. The dams were analyzed for existing conditions; at future conditions (including the next two expected dam raises to elevations 1,230 and 1,245 feet); and at the ultimate condition at elevation 1,315 feet (see Figures 1.1, 1.2, and 1.3). These analyses provide a framework for the development of future design and construction plans up to elevation 1,245 feet. The evaluation also provides a conceptual review of the stability of the dams at the ultimate elevation 1,315 feet. The analyses concentrate on evaluating the safety factors at each elevation based on proposed dam configurations. The following sections of the report outline the objectives and scope of this report; present design issues; provide details on the methods of analysis; complete seepage and stability analyses; summarize engineering evaluation for the dams; comment on computed safety factors; and make conclusions and recommendations for future design, construction, and monitoring.

2.0 Objective and Scope

Barr completed an evaluation of the seepage and stability of Dams 1, 2, and 5 in 2009. The objectives of the evaluation were:

- Gain a better understanding of how seepage occurs through the dams and how the fine tailings perform as a seepage cutoff;
- Understand the variation in seepage at the proposed conditions of pond and toe water elevations and for variations in permeability;
- Evaluate the stability of the dams simulating circular and block failure surfaces in both drained and undrained analyses;
- Evaluate the behavior of the dams as a result of variations in the strength parameters for the lacustrine clay foundation;
- Develop concepts for construction of the next two dam raises to elevations 1,230 and 1,245 feet, respectively;
- Evaluate the seepage and stability at the ultimate basin elevation of 1,315 feet; and
- Provide a basis for long-range planning when laying out dam slopes, dam crests and alignments; reviewing seepage at the dams; evaluating instrumentation, data, and plans; and performing closure of the tailings basin.

The evaluation at the ultimate basin elevation is not intended to be the final analysis of the dams. Evaluation of dam stability is an ongoing process and should follow the Observational Approach. The Observational Approach is based on performing analyses using available information and measurements from the field to verify the dam design. In the analyses contained in this report, the available information is used to create a series of predictions of performance for reasonable average and lower-bound conditions. The stability of the dams should always be evaluated or updated using available information when design features, construction methods, or field measurements change.

The basis for the new dam cross section configuration is presented in Barr's 2003 report entitled, "Preliminary Evaluation of Dams 1 and 2 and Review of Dam 2 at Northshore Mining Tailings

Basin." This report defines the downstream slope of the upper portion of the dam as 6H:1V and recommends a proposed filter berm and fine tailings beach for a seepage cutoff.

The following tasks were completed to achieve the above-described objectives:

- Preparation of a detailed geotechnical investigation that reviews the historical geotechnical data and provides a source of geotechnical information for future dam design at the basin. The report was submitted to NSM in July 2009 and is titled, "Geotechnical Evaluation Report for Dam Construction and Foundation Materials." The evaluation included the estimation of seepage and strength parameters for the different materials used in the stability modeling software computer simulations.
- Development of representative geotechnical cross sections of Dams 1, 2, and 5 for the seepage and stability analyses.
- Performance of seepage analysis and calibration of the modeled cross sections for Dams 1, 2, and 5 for existing conditions and comparison of the results to existing monitoring data, when available.
- Performance of seepage analysis of Dams 1, 2, and 5 for future conditions to predict future seepage and pore-water pressures for use in stability modeling.
- Performance of slope stability analysis for existing conditions to compute the factor of safety using the limit-equilibrium method and a comparison to available deformation monitoring data.
- Performance of slope stability analysis for future conditions to compute factors of safety using limit-equilibrium methods.
- Provision of recommendations for future design, construction, and monitoring based on the results of the analysis.

The report is organized to first describe the methodology used in the engineering analyses and then present the results of the analyses (both seepage and slope stability) for Dams 1, 2, and 5. The analyses use the recently presented design parameters in the models to predict performance, and compare the predicted behavior with the measured performance from the instrumentation and observed conditions. A summary of the conclusions and recommendations are presented at the end of the report.

3.0 Design Issues

Tailings basins encompass many areas of engineering which should be considered during the design process of the facility. This report specifically discusses the seepage and stability of the dams with respect to the existing and planned configurations. A discussion of the dam configuration and other issues related to the future design are discussed in the following sections.

3.1 Dam Geometry

In 2003 a new design for Dams 1 and 2 was proposed due to an anticipated shortage of plant aggregate for dam construction material. The plant aggregate was required for use in changing railroad alignments, upgrading the West Ridge Road, and constructing the dams. The new design, as shown on Figures 1.1, 1.2, and 1.3, consists of an offset upstream dam in which the seepage cutoff is relocated approximately 800 feet upstream of the previous seepage cutoff. As part of the offset upstream construction, the updated dam cross section has a 6H:1V downstream slope. The design also incorporates a ditch to collect seepage water above the glacial-till cutoff and route the water to the seepage collection pond at the toe of the dam. The fine tailings are discharged into the basin upstream of a filter berm and will be used for the seepage cutoff. Dam 5 remains a centerline construction dam, and no significant changes to its configuration are proposed at this time.

In 2003 when the current dam design was proposed, certain information was identified as critical for the evaluation of the long-term performance of the dam, specifically the strength and permeability of the foundation soils and the fine tailings. The dam foundation is lacustrine clay, which exists under nearly all of the dams in varying thicknesses. Overconsolidated lacustrine clay is located near the toe of the dams and normally consolidated clay exists under the main portion of the dams. The fine tailings are located underneath the plant aggregate and above the clay and also upstream of the proposed dam raises. The tailings are hydraulically placed so they are susceptible to liquefaction.

3.2 Dam Issues

A review of the dams at the tailings basin identified the following issues which were considered in the evaluation:

- Seepage through the dams
- Stability of the dams

The following sections describe these issues.

3.2.1 Seepage through the Dams

The seepage through the dams is an important aspect to the overall design of the tailings storage facility because it impacts the seepage collection systems and stability of the dams. The intent of the revised dam design for Dams 1 and 2 was to reduce the material required for construction of the dams and to use the fine tailings beach as a method for seepage cutoff. Therefore in order to include the effects of seepage into the stability of the dams a seepage analysis was required.

As discussed in detail in later sections of the report, seepage models were created for each dam. The models were developed using the permeability values proposed in Barr (2009) using steady state conditions assuming constant total head at the tailings pond and seepage collection pond locations, where appropriate.

3.2.2 Stability of the Dams

Plant aggregate is used to construct the dams that contain the fine tailings at the tailings basin. Sometimes the amount of plant aggregate available for dam construction varies based in part on the production of the plant as well as other uses for the tailings. After being delivered via train to the basin, trains dump the plant aggregate, which is moved with heavy equipment to areas of the dam that require construction. Typically the plant aggregate is dumped into 8-to-10-foot-high piles, then a rubber-tired bulldozer levels off the piles.

The dams are typically raised by placing the construction material near the filter berm on the downstream side and working downstream to the face of the slope, thereby stabilizing the downstream face of the filter berm and quickly increasing the height of the crest of the dam and creating the pond freeboard required for operation. This process is repeated along the dam alignment until the dam is raised.

The fine tailings located within the dam have a relatively high coefficient of consolidation and therefore pore-water pressure dissipation is rapid and the pressures developed due to the typical dam construction method dissipate quickly. At this time monitoring data obtained during normal operations of dam construction do not indicate significant pore-water pressure effects that would cause significant impacts to dam stability. The fine tailings are also susceptible to liquefaction because they are hydraulically placed within the confines of the dams. The effects of liquefaction will be addressed in the stability analyses.

A stable foundation is important as the dams continue to rise to elevation 1,315 feet over the course of the next 60 years. The lacustrine clay located within the foundation is subject to pore-water pressure increase from rapid fill placement which could lead to instability. Pore-water pressures in the lacustrine clay were measured with cone penetrometer dissipation tests and with piezometers within the foundation upstream of the glacial till cutoff during the geotechnical investigation. The results indicate that the pressures within the clay foundation are hydrostatic and not elevated due to fill placement. The tests also indicate that the pore-water pressures within the foundation clay are likely to drain upward into the fine tailings and downward into the foundation till. The tests were performed and instrumentation data collected at specific points in time during the construction process. Due to drill-rig access requirements, construction fill was not placed nearby for a period of time. Likewise monitoring is performed twice a year (or as needed) and may not capture elevated pore-water pressures during those monitoring events. Data acquisition systems could be used to capture pore-water pressure response within the foundation on a more continual process during fill placement and addressed later. The stability analyses address the effect of varying modes of failure, such as block or circular shapes, as well as variations in strength within the clay and fine tailings.

4.0 Engineering Analysis Methodology

4.1 General

The dams located at the tailings storage facility were analyzed for both seepage and stability. The method of analysis chosen for this report was the traditional limit-equilibrium approach. In the limit-equilibrium approach the soil is assumed to be at the state of limiting equilibrium and a factor of safety is computed. The limit-equilibrium method has been used for all previous analyses by Klohn and Sitka. In 2003 Barr used both the limit equilibrium method and performed some preliminary deformation-based analyses.

In past investigations Klohn and Sitka used instrumentation data to calculate the total head within the dam cross sections. The total head values were then used to create a phreatic surface across the dam and the information was used to calculate the seepage forces on the failure surface. Because of the different materials within the dam section, multiple phreatic lines were required in some instances to represent the differing total heads within those materials, complicating the model and stability assessment. This evaluation uses an updated method for computing the seepage effects which integrates seepage and slope stability modeling software. The integration incorporates the permeability of the individual layers within the dam to calculate seepage and the seepage forces are incorporated into the stability analysis. The modeling techniques, assumptions, and limitations of the approaches used are described below.

4.2 Seepage

The main objective of the seepage analysis is to develop a good understanding of the groundwater flow and how it is related to the stability of the dams. Groundwater plays a major role in the stability and construction sequence of the dams. Barr emphasized the evaluation of the parameters recommended in the geotechnical report. These parameters were based on laboratory and in-situ testing that model the most relevant hydrogeologic materials and match the model results to the observed field performance. Since the parameters are presented as a range of expected values, calibration and subsequent simulations predicted groundwater conditions for various dam elevations. The seepage simulations presented in this report model groundwater flow for steady-state conditions. The simulations do not consider the impact from transient conditions such as fill placement and pore-water pressure rises or decreases; precipitation; and other conditions.

The seepage analysis is an important aspect of the modeling process. For complicated cross sections such as those found within the tailings dams, the use of estimated phreatic surfaces may lead to unconservative models. Therefore the computer model used to create a flow net is also used to evaluate seepage flow through dams. The computer model uses the flow net to calculate the dam cross section seepage forces, which are then incorporated into the slope stability model. This method is in contrast to relying on an estimated phreatic surface developed from piezometer readings in which seepage forces are ignored within the model. The seepage forces should be representative of those in the dam provided the model is calibrated using the range of permeabilities recommended from test results from the previous geotechnical studies. Additionally monitored piezometers, seepage flow, and relief wells are typically used to evaluate the accuracy of the seepage models.

4.2.1 SEEP/W 2004 Software

The seepage was modeled using SEEP/W, a computer modeling program developed by Geo-Slope International. SEEP/W uses the finite-element analysis technique to model the movement and pore-water pressure distribution within porous materials, such as soils. This method was chosen because comprehensive formulation makes it possible to analyze both simple and highly complex seepage problems. SEEP/W can formulate saturated and unsaturated flow, steady-state and transient conditions, and a variety of boundary conditions. Model integration (SEEP/W and SLOPE/W) allows the use of seepage files in limit-equilibrium slope-stability analysis. SEEP/W generates an output file containing the heads at the nodes of the finite-element mesh. The integration of Geo-Slope products allows the use of the SEEP/W head file in the slope stability program to compute the effective stress. Therefore, it allows evaluation of the seepage impact on stability. This information was used to evaluate stability under steady-state conditions of the dams.

4.2.2 Seepage Mesh and Boundary Conditions for Existing Conditions

In the development of the existing conditions seepage model, a finite element mesh was created to conform as closely as possible to the conditions shown in Figures 1.1, 1.2, and 1.3 for each dam section, although different coordinate systems were used to simplify the model’s creation. Quadrilateral and triangular isoparametric elements were used to build the mesh, in accordance with the geometry lines of both surface and subsurface conditions.

The boundary conditions for Dams 1 and 2 were defined by setting a constant total head at the nodes located at the top of the upstream fine tailings. The fixed total head was set at elevation 1,203 feet, corresponding to the approximate pond elevation at the time of the piezometer monitoring. Potential seepage-face review nodes were placed on the downstream face of the dam to facilitate this process. These nodes allow the model to check for possible boundary seepage.

In addition a flux section was modeled near the seepage collection ditch, which is located on the upstream face of the glacial till cutoff. Flux sections have the ability to calculate the amount of groundwater flow passing through them per unit width of the dam. Thus the values reported at the flux section can be used to estimate the amount of water being collected at the seepage collection trench and can be compared to measured values and used for calibration.

Finally infinite elements were placed along the entire upstream and downstream subsurface boundaries. Infinite elements minimize boundary effects by allowing the user to define the behavior of the problem beyond the extents of the finite element mesh. Layers at the upstream boundary are extended infinitely and horizontally in the upstream direction, while the same phenomenon is occurring at the downstream boundary. The model configuration for both Dam 1 and Dam 2 are shown in Figures 4.2.2a and 4.2.2b respectively.

As in the analysis performed by Barr in 2003, relief wells were not incorporated into the seepage model as elements. There are many relief wells at different elevations and locations along Dam 1 and many of them are inaccessible. At Dam 2 only a couple of the relief wells have been located. Dam 5 does not have any relief wells. Additionally, true water-level readings are not obtained in all of the relief wells during routine monitoring due to the lack of accessible outlet at many locations. This information could not be input to the model. However sometimes the flow rate of seepage through the toe of the dam can be compared to the values measured in relief wells. Many of the relief wells as shown on Drawings 1110 and 1210 of Sitka (1996) are submerged below the seepage collection ponds on Dams 1 and 2. For this study, a better match between measured and computed piezometer levels could be obtained without incorporating the relief wells within the model.

For the analyses at Dam 5, boundary conditions were defined by setting a constant total head at the nodes located on the upstream side of the crest and at the toe of the dam. To correspond with measured pond levels, the heads at the toe of the dam were set at elevation 1,170 feet. The total heads on the upstream side of the crest were fixed at elevation 1,199.5 feet, the pond elevation measured during piezometer monitoring. These total heads were applied both on the upstream boundary of the model to correspond to the pond level at a location approximately 150 feet upstream from the downstream edge of the glacial till cutoff and also at elevation 1,199.5 feet. The seepage model configuration for Dam 5 is shown in Figure 4.2.2c. One assumption of the seepage and slope stability model for Dam 5 is that the lacustrine clay and foundation till extend horizontally from the toe of the existing dam to the toe of the proposed dam at various crest elevations. This assumption should be confirmed in the future because at this time access is not possible due to the very soft organic deposit and pond at the toe of the dam. Access will be possible after completion of the remainder of the toe filter and drain construction. The assumption is conservative. Significant rock outcroppings exist near the dam area. It is feasible that the rock is at much shallower depths than assumed in the model.

4.2.3 Seepage Mesh and Boundary Conditions for Proposed Conditions

The finite element mesh was created to conform as closely as possible to the proposed conditions for Dam 1, Dam 2, and Dam 5, as shown in Figures 1.1, 1.2, and 1.3 respectively. Quadrilateral and triangular isoparametric elements were used to build the mesh in accordance with the geometry lines for the proposed configuration. The dam geometry will be discussed in more detail in later sections of this report.

Boundary conditions were defined in similar manner to those used for the existing geometry. The only difference was that the total head nodes at the top of the upstream fine tailings were altered so that they were always 10 feet lower than the crest elevation to correspond to the minimum freeboard on the dams. Thus, they were set at elevations 1,220 feet, 1,235 feet, and 1,305 feet for crest elevations of 1,230 feet, 1,245 feet, and 1,315 feet, respectively. This is a conservative application of tailings pond water level but represents a real condition where a flood occurred and the dams were required to store the water until the water treatment plant and the ore beneficiation process could lower the pond level. Because the reduction in water level would take a significant amount of time, the dams would reach a steady state condition near the elevated water level. As discussed in the existing conditions analyses, potential seepage face review nodes, flux sections, and infinite elements were included in the models for Dam 1, Dam 2, and Dam 5. The modeled cross sections are shown at the ultimate condition as Figures 4.2.3a, b, and c respectively.

4.2.4 Seepage Analysis Calibration

The calibration of the seepage models is a very important aspect to the analysis of flow conditions. The calibration allows for comparison of anticipated conditions through the use of a model and real conditions identified through instrumentation and observations. The seepage model provides input in the slope stability model which affects the stability of the dams. Therefore, a methodical process is required to calculate the anticipated flow conditions in the dams. This process is described below.

Comparison of design permeability values through actual field performance of piezometers and seepage measurements is a method for validation of seepage models. After developing the model mesh, boundary, and flow conditions, a seepage analysis was performed on the dams under the existing conditions.

Models of the existing conditions were created by using the recommended ranges of design permeability values presented in Barr (2009). Because the permeability values were based on laboratory and field data, the permeability for most of the material types were held, when possible, to the recommended range in values presented in Table 4.2.4 during the analysis. Due to the range in permeabilities of some of the materials, they were altered in order to match measured piezometer levels and flow rates in the seepage channel and at the toe. These materials were the overconsolidated lacustrine clay and sand and gravel from the starter dam construction as well as the normally consolidated lacustrine clay. Other materials such as the fine tailings, plant aggregate, and filter tailings were not altered because either there are significant numbers of tests validating the values recommended or the materials have little effect on the calculation of total heads and seepage pressures. In some cases, such as Dam 1, anisotropy is used in the analysis for three materials: foundation till, normally consolidated lacustrine clay, and overconsolidated lacustrine clay. The model was set up so that, when the permeability of a material was changed to match field measurements, the anisotropy remained fixed. In previous studies by Sitka, Klohn, and Barr, anisotropy was measured in permeability samples, which were included in the models.

The methodology used for this analysis first evaluated the calculated seepage computed by the model and then compared the computed seepage to the observed seepage measurements on the dam. The measured total heads in the piezometers were compared to the total heads computed from the models. Several iterations and changes to the permeability values were required until the differences between measured and computed total heads were within a reasonable range. Since the dams are constructed of materials that are very heterogeneous in nature, variations on overall permeability can be expected. As such, the recommended values are suggested for the calibration process and modifications to the values should be made to match the field observations. The calibration process was used for the existing conditions because instrumentation data were available. For the proposed conditions the analysis used the calibrated parameters determined in the existing conditions model to calculate the total heads within the model and predict future total heads.

4.3 Slope Stability

The objective of the stability analyses is to assess the dam stability in terms of factor of safety. The projected ultimate dam crest elevation is 1,315 feet. The revised slope and upstream cutoff design that Barr designed in 2003 were used to complete analyses of the dam's performance in the near-term and at the ultimate configuration for this study. The stability was evaluated using SLOPE/W 2004.

4.3.1 Limit Equilibrium

The tool used in the limit-equilibrium modeling of the dams was GeoStudio 2004, which includes the seepage and slope stability analysis. This is a two-phased approach in which the steady-state flow conditions and seepage pressures are determined first and then the factor of safety of the slope is calculated using the seepage pressures.

4.3.2 SLOPE/W 2004 Software

The slope stability analyses were conducted using SLOPE/W, a computer-modeling program developed by GEO-Slope International. SLOPE/W uses the limit-equilibrium theory to compute the factor of safety of earth and rock slopes. It is capable of modeling a variety of methods to compute the factor of safety of a slope while analyzing complex geometry, stratigraphy, and loading conditions. As previously discussed, to compute effective stress, SLOPE/W allows importation of the head file from the seepage analysis. As a result, this approach incorporates the calculation of seepage forces when computing the factor of safety.

Integrating seepage pore-water pressures and slope stability results in a more suitable calculation of factor of safety than traditional limit-equilibrium software, which uses a phreatic line to simulate groundwater. Pore-water pressures for the soil slices are computed from a flow net, which allows the incorporation of seepage forces when calculating the factor of safety. This method differs from Sitka's approach in 2002 and other analyses by Klohn, which were conducted using phreatic lines estimated from the instrument readings to simulate the groundwater conditions.

4.3.2.1 Factor of Safety Calculation

Spencer's method was used to calculate the factor of safety of the dams in this stability analysis. This method is considered adequate. It satisfies all conditions of static equilibrium and it provides a factor of safety based on both force and moment equilibrium.

4.3.2.2 Searching Technique for Critical Failure Surface

In SLOPE/W the critical failure surface can be circular, block, or user-specified. In the circular and block searching technique the grid of circle-centers (or center of block) and radius (or ends blocks) are established by the user, and then the computer program searches for the circle or block yielding the minimum factor of safety. The user completely defines the shape of the failure surface in the user-specified technique. The factor of safety is computed for that particular surface.

It is necessary in the limit-equilibrium approach to specify the shape of the critical failure surface (circular, block, log spiral, piecewise linear, etc.) in advance. For these analyses the grid- and radius-searching technique for the circular failures and a modified grid and radius method for the block failure techniques was used. The modified block failure technique will be discussed in later sections of the report.

4.3.2.3 Drained and Undrained Stress Analyses

During the 2003 analyses by Barr and previous analyses by Sitka and Klohn, the lacustrine clay foundation was found to be a critical component in the stability of the tailings basin. Due to this fact extensive testing has been completed using direct simple shear testing. Additionally historical triaxial testing results were compiled and used in the analyses to further develop strength envelopes for the lacustrine clay in compression loading. The geotechnical parameters for the lacustrine clay are presented in Barr (2009).

The fine tailings are a significant unit addressed in these analyses. Fine tailings are sand to silt-sized material with less than 10 percent clay-size fraction (less than 2 micron size). These tailings were tested using various methods to evaluate the drained and undrained yield and liquefied strengths in Barr (2009). These parameters are important because, as the dams rise, construction will continue to occur over the buried fine tailings zone of Dams 1 and 2.

The modeling procedure included evaluating the dams for the total stress or undrained loading in the undrained shear strength analysis (USSA) and the effective stress or drained loading in the effective shear strength analysis (ESSA). In the analyses, both the direct simple shear strength (DSS) and the triaxial compression strength (TXC) envelopes were used for the lacustrine clay. The mode of failure was evaluated for the circular failure and block failure. Block failure of the dam was assessed assuming that the foundation glacial till was impenetrable in the model, thus forcing the failure through the lacustrine clay foundation in a block shape.

This is a realistic assessment due to the significant contrast in strength between the lacustrine clay and glacial till. The strength of the lacustrine clay was varied in the analysis from the average to lower-bound for each of the DSS (block failure) and TXC (circular failure) analysis. The strength parameters used in the analyses are shown in Table 4.3.2.3, which was presented in Barr’s 2009 report, and graphically in Figures 4.3.2.3a, b, c, and d. The variation between the lower-bound and average strength allows for conservatism in design and for the evaluation of sensitivity of strength of materials.

4.3.2.4 Liquefaction Analyses

Liquefaction refers to the post-yield undrained behavior of contractive sands (Casagrande, 1936, 1975). Loose sands respond to sustained shear stress in a contractive manner in which the pore-water pressures increase and the undrained shear strengths substantially decrease. When the sand liquefies, its resistance to deformation levels off at a small undrained shear strength, which is called liquefied shear strength. The liquefaction phenomenon has also been observed in mine tailings, which are hydraulically deposited and exhibit loose conditions (Castro, 2003). Liquefaction can be triggered by either static or dynamic loads, or by deformation under a static shear stress that is larger than the liquefied shear strength.

The yield shear strength ($Su_{(yield)}$) of a saturated, contractive, and sandy soil is defined as the peak shear strength available during undrained loading (Terzaghi, et al., 1996). The shear strength mobilized at large deformation is the liquefied shear strength ($Su_{(liq)}$). The yield and liquefied shear strength ratios are the yield and liquefied shear strengths normalized with respect to the vertical effective stress within the zone of liquefaction prior to failure, respectively.

It is anticipated that in most cases loading or change in load within the fine tailings/slimes will be slow enough for the tailing to be sheared under drained conditions. However there may be circumstances in the field during which rapid changes in load and/or local stresses may occur that can lead to undrained loading. It is possible for liquefaction to occur if a rapid change in stress is applied to the dam in the form of an earthquake; reduction in toe resistance; placement of fill; a significant precipitation event that rapidly increases the pond level and phreatic surface; or in other ways. Initially the change from normally drained to undrained shearing may be localized, but the load decrease in resistance may lead to a rapid transfer of shear stresses to adjacent soil zones. These adjacent zones then behave as if under undrained conditions, eventually leading to overall undrained behavior of the fine tailings/slimes.

4.3.2.4.1 Seismicity of the Area and Ground Motions

Northern Minnesota is not a highly active seismic zone. In fact, Minnesota has one of the lowest levels of earthquake occurrence in the United States. Only 19 small to moderate earthquakes have been documented in Minnesota since 1860. Table 4.3.2.4.1a summarizes the earthquake history in the state of Minnesota. The earthquakes listed in Table 4.3.2.4.1a are associated with minor reactivation of ancient faults in response to stress changes and shows that only eight out of the nineteen earthquakes have been recorded, whereas eleven of them are based on the magnitude intensity from felt reports.

According to Table 4.3.2.4.1a, the strongest documented earthquakes are associated with 1917 Staples earthquake (magnitude 4.7 to 5.0) and the 1975 Morris earthquake (magnitude 4.6 to 4.8). Near their epicenter these earthquakes caused objects to fall, cracked masonry, and damaged chimneys. A more recent and less dramatic event was the 1993 Dumont earthquake. The magnitude of this earthquake was 4.1 and impacted an area of 69,600 km^2 with associated intensity of V-VI near the epicenter. The shaking near the epicenter was accompanied by a loud, explosive noise that alarmed many people, but no injuries or serious damage occurred (Chandler, 1994). The current knowledge indicates that a severe earthquake is very unlikely in Minnesota. Weak to moderate earthquakes do occur occasionally. The threat from such events is very small compared to other natural hazards.

The performance of a detailed seismic evaluation of the facilities requires estimating ground motion parameters. The goal of an earthquake-resistant design is to produce a structure that can withstand a certain level of shaking without excessive damage. Typically, this results in the performance of a probabilistic seismic hazard analysis (PSHA). Due to the low seismicity of the project area and the character of this evaluation, a PSHA was not performed for this project. A seismic risk calculation of ground motion was prepared based on the United States Geological Survey (USGS) web site, which contains information about seismicity in the United States. This calculation is considered sufficient for this application.

The USGS Web site (http://earthquake.usgs.gov/research/hazmaps/interactive/index.php) was used to perform the seismic risk calculation. The results of the USGS web report are shown as Table 4.3.2.4.1b and summarized in Table 4.3.2.4.1c. Table 4.3.2.4.1c summarizes the ground motions for different probabilities of exceedance and shows that the peak ground acceleration at the site for a 2 percent probability of exceedance in 50 years is 0.024 g. This corresponds to a 0.0004 probability of exceedance per year or a return period of 2,475 years.

The seismic stability assessment was incorporated into the analyses for this project in the liquefaction evaluation. The use of pseudo-static stability analysis is considered inadequate because, among other reasons, it uses horizontal acceleration and applies the forces to the failure surfaces. Earthquake forces only act for a short time and are applied in multiple directions. Therefore it was assumed that a moderate earthquake will impose rapid loading, resulting in undrained conditions, on the embankment. This event can trigger liquefaction of the fine tailings/slimes. As a result the analyses incorporate the earthquake impact by evaluating the post-liquefaction stability using the liquefied strength of the fine tailings. The analysis procedure is discussed in the following sections.

4.3.2.4.2 Slope Stability Analyses

The previous section discusses the seismicity of the project area and shows that low magnitude earthquakes may occur. These findings and the potential triggering events discussed in previous sections indicate that it is prudent to design the dam to be stable in undrained conditions. This evaluation is most relevant for offset upstream construction because the base of the offset dam is founded upon soft fine tailing/slimes, which are susceptible to liquefaction. The fine tailings/slimes are susceptible to liquefaction because they are hydraulically deposited, which results in a very loose condition.

The following presents a detailed description of the method of analysis and assumptions of the liquefaction evaluation at the tailings basin. The results of the liquefaction evaluation are presented in each section associated with each dam.

Methodology

Castro (1969) showed that the liquefied shear strength $Su_{(liq)}$ of a given sand is primarily a function of the void ratio. Poulus, et al. (1985) and Castro, et al. (1995) proposed a methodology to evaluate liquefaction. In their approach the shape and slope of the steady-state line is determined by using triaxial test results to define the relationship between void ratio (e) and liquefied shear strength $Su_{(liq)}$ or effective minor principal stress (σ'_3). The methodology then involves evaluation of the in-situ void ratio and use of the liquefied strength for material identified as contractive. The methodology proposed by Castro was a breakthrough in liquefaction evaluation when it was first introduced. The approach requires modifications and several corrections because $Su_{(liq)}$ is plotted in logarithmic scale and changes rapidly with small changes in void ratio. Additionally it is extremely difficult to determine the in-situ void ratio of cohesionless soils (Terzaghi, et al., 1996). In the case of mine tailings, even samples taken with Osterberg samplers undergo disturbance, which induce changes in the void ratio and thus significantly affect the undrained shear strength (Walton, et al. 2002). This approach was also attempted at the Northshore tailings basin with mixed results. As a result it was necessary to use an approach that utilizes in-situ testing data and does not require in-situ void ratio correction/determination.

The in-situ test method used to measure the undrained shear strength of the fine tailings/slimes was the cone penetration testing (CPT). Most of the fine tailing/slimes within the Northshore tailings basin do not exhibit excess pore-water pressure during cone penetration (at standard penetration rate 2 cm/s), resulting in drained or partially drained conditions during penetration. As a result, it was necessary to perform CPT at faster penetration rates to achieved undrained conditions that could be measured. The methodology and results of the CPT evaluation are discussed in Barr (2009). After soundings are performed, the CPT data are processed to calculate a range of values for the undrained shear strength ratio. Triaxial testing on remolded samples was performed to evaluate the liquefied strength of the tailings. The results of the testing are presented in Barr (2009) and discussed in subsequent sections of this report.

The analysis is conservative because it assumes that the whole mass of the fine tailing/slimes liquefies and mobilizes a given strength ratio value. This is especially true during the later phases of construction. In this modeling there is an implicit assumption that no strength-gain occurs within the fine tailing/slimes between now and the construction of these future raises. This assumption is conservative, because strength-gain has been observed and measured at other tailings basins in Minnesota.

4.4 Model Parameters

This section discusses the different parameters used for the seepage and slope stability calculations. The parameters were developed during a review of previous data and additional field investigations in 2005 and 2006 and are addressed in Barr (2009). These parameters are summarized in the following sections.

4.4.1 Permeability

The main parameter associated with materials relevant to seepage analysis is the hydraulic conductivity otherwise known as permeability. A significant review of historical data and new permeability testing is provided in Barr (2009) and proposed parameters are presented in Table 4.2.4. Although parameters are recommended in the table, the materials within the dam are heterogeneous and should be expected to vary throughout the dams. The presented materials parameters, therefore, require some validation with the monitoring data collected at the tailings basin. The process for validating the permeability parameters will be discussed in later sections of the report.

4.4.2 Shear Strength

The shear strength of materials encountered at this site has been studied extensively since the inception of the project in the late 1970s. The initially derived geotechnical parameters have been updated throughout the years as the dams were raised and more information became available through explorations. The most recent update was completed by Sitka in 1996 where additional testing of the plant aggregate and lacustrine clays was performed. The Barr (2009) study provides a summary of the previous work and detailed discussions regarding the new data obtained for the lacustrine clays and fine tailings. Table 4.3.2.3 provides a summary of those model parameters proposed for this study. The strength of the materials is presented as a friction angle where appropriate. For other materials strength is represented in the table as an undrained shear strength ratio. Others are more explicitly represented in the models as strength envelopes developed from the previous data.

For this evaluation a series of strength envelopes was created to use in the models. Due to concerns that foundation stability plays a significant role in the overall stability of the dams, the lacustrine clay has received considerable attention over the years. Updates to the strength data have been recently addressed. After reviewing the results of the strength analyses, the lacustrine clay was an obvious choice for representation by strength envelopes rather than a simple Mohr-Coulomb approach. The strength envelope more accurately represents the strength behavior overall at various stress levels and for differing types of shear, like DSS or TXC. Strength envelopes were created for the failure mechanism that most generally reflects a zone of compression similar to TXC or plane-strain as in the DSS test. Strength envelopes were then developed based on the lower-bound value and the average value for the data set to evaluate the sensitivity of the factor of safety of the dams and the strength of the foundation materials. The foundation clay was then represented by four strength envelopes in the model: TXC average; lower-bound values; DSS average; and lower-bound values. The strength or failure envelopes are shown as Figures 4.3.2.3a and b for the USSA (undrained) and Figure 4.3.2.3c and d for the ESSA (drained).

The fine tailings strength required a significant amount of study. At Dams 1 and 2 fine tailings exist under some portion of the main dam. Fine tailings are deposited hydraulically, and due to the nature of this type of deposition, fine tailings are contractive in nature. Therefore, as shown in Table 4.3.2.3, the yield strength ratio and the liquefied strength ratio of the fine tailings were evaluated as part of Barr (2009). The other focus of the stability analyses are the parameters of the lacustrine clay strength envelopes. A process was developed to vary the strength parameters and analysis methods for the USSA since it was a more complicated approach than for the ESSA, as shown as Table 4.4.2.

The table shows how the foundation strengths were varied for both the yield and liquefied strength analysis in the fine tailings zone.

4.4.3 Recommended Minimum Factors of Safety

Typical acceptable factors of safety for dam stability—1.3 for the USSA analysis and 1.5 for the ESSA analysis—were used for this study. These values can be adjusted based on many factors, including the frequency and intensity of monitoring; knowledge of existing geo-materials; calibration of the stability models; sensitivity within the range of acceptable strength parameters; conservatism in the model or parameters; and sophistication of modeling software.

A factor of safety of at least 1.2 provides an adequate degree of conservatism in analyses related to flow liquefaction. The liquefied shear strength is the minimum strength that a liquefiable material can mobilize. A factor of safety less than 1.2, therefore, may be acceptable in a conservative analysis procedure. Olson and Stark (2002) and Castro (2003) recommend a factor of safety between 1.0 and 1.1 for typical flow liquefaction analyses. If the factor of safety against flow liquefaction is less than or equal to unity, flow liquefaction is predicted to occur. If the factor of safety is between 1.0 and 1.1, some deformation probably will occur. A factor of safety of 1.05 was used for the liquefied strength analysis in this report which follows the guidelines of Olson and Stark (2002) and Castro (2003).

4.5 Assumptions and Limitations

The seepage simulations presented in this report modeled the flow under steady-state conditions. The seepage analysis did not incorporate excess pore-water pressure that is associated with loading such as dam construction. In other words it was assumed that the rate of construction was approximately 10 to 15 feet over 3 to 5 years. This construction rate is slow enough that no excess pore-water pressures are generated in the tailings or foundation materials. This assumption, similar to those in previous reports, is based on instrumentation readings measured throughout the life of the basin. Therefore staged construction is not addressed in this report. The dams were evaluated for liquefaction by assessing the liquefied strength of the materials and incorporating those strength parameters into the models.

5.0 Dam 1 Evaluation

Dam 1 is located on the southern end of the tailings basin. Figure 1.1 shows the typical dam cross section in schematic form. The dam is underlain by lacustrine clay deposits 10 to 20 feet thick and glacial till of varying thickness, with bedrock at varying depth below the till. The dam was initially constructed as a sand and gravel starter dam with an upstream glacial till cutoff. The original intent was to raise the dam using downstream construction methods. This was changed to the upstream construction method in 2003. A filter berm was constructed at Dam 1 approximately 800 feet upstream of the starter dam, and tailings are discharged onto the beach. The area downstream of the filter berm is constructed with plant aggregate placed over fine tailings previously deposited by pipeline from near the original starter dam. The plant aggregate zones are currently approximately 40 feet thick, and the fine tailings are about 50 feet thick. The dam crest elevation was about 1,215 feet in 2007 at the time the modeling process began. The starter dam crest is at about elevation 1,195 feet. The proposed overall upper dam downstream slope, as shown on Figure 1.1, is about 6H:1V for an ultimate upper dam height of about 120 feet, ending at a crest elevation of 1,315 feet. Sheets G-02 to G-05 (Appendix A) show additional details of Dam 1. In the future NSM plans to pursue plans to create a plant aggregate stockpile area downstream of the existing toe of the dam. The stockpile will be used for future construction projects and for possible use during closure of the tailings basin.

Two cross sections (28+40 and 35+00) had historically been identified as critical areas of study during the initial phases of design and cross section. These cross sections are located near the middle of the dam in the area of the highest potential dam raise, also identified as the lowest natural ground foundation area in the area of soft lacustrine clay deposits. Recently performed CPT soundings and standard penetration (SPT) borings were used to verify and slightly alter the Sitka (1996) geotechnical cross section. The section used in the analysis of existing conditions is shown in Figure 1.1. The analyzed section incorporates the 2007 Barr survey, which includes the plant aggregate at elevation 1,217 feet and updated stratigraphy as presented in Barr (2009). A composite cross section for Dam 1 was developed, which incorporates the features from the highest section of dam that is founded on the lacustrine clay.

The proposed conceptual ultimate dam configuration is also shown in Figure 1.1. A vertical filter tailing zone extends from the existing elevation of about 1,215 feet to the ultimate elevation of 1,315 feet in the proposed conceptual configuration. The downstream slope of the dam will slope down from the crest at 6H:1V to the existing perimeter dam. The downstream shell will be constructed of plant aggregate material, while fine tailings will be deposited upstream of the filter berm to create a seepage cutoff. Figure 5.0 shows a schematic of the general groundwater flow from the tailings. This diagram shows how the seepage cutoff is utilized and how groundwater flows through the dam cross section.

5.1 Seepage Analysis under Existing Conditions

A seepage analysis was performed on Dam 1 under existing conditions using the recommended permeability values. First the dams were analyzed and the computed seepage values were compared to the observed seepage data. Second, the calculated piezometer pressures were then compared to the observed values from monitoring events. The following sections describe the results of the calibration of the seepage models.

5.1.1 Comparison with Field Performance

The seepage models were evaluated by comparing the calculated conditions to the observed conditions at the dam. To complete the model calibration permeability values of two material types were altered in order to match measured piezometer total head and flow rates in the seepage channel and at the toe. These materials were the lacustrine clay and sand and gravel from the starter dam construction. Anisotropy was used in the analysis for three materials: foundation till, normally consolidated lacustrine clay, and overconsolidated lacustrine clay. Anisotropy was not varied in these analyses. The following sections present the details of the calibration procedure.

5.1.1.1 Calculated Seepage vs. Measured Flow

The first method for calibrating the model uses the seepage ditch flow measurements. On September 1, 2006, the flow rates for the west and east weirs at the ends of the ditch were calculated as 819.6 and 357.7 gallons per minute (gpm), respectively. The combined flow-rate over the dam length of 5,189 feet was 1,177.3 gpm. In the seepage collection ditch the unit flow rate at Dam 1 was 0.23 gpm/ft. The permeability values used in the model shown in Table 4.2.4 were varied through several iterations until reaching a computed flow rate of 0.16 gpm/ft in the seepage collection ditch. This resulted in a difference of about 30 percent from field measurements.

This is considered a fairly close match due the variability of stratigraphy, expected variability in permeability in the dam cross section over the entire length of the seepage collection ditch, and possible impacts due to precipitation events. The highly variable nature of precipitation on the plant aggregate surface and infiltration into the dam could result in variable observed seepage at the weirs.

Additionally, the seepage collected in the ditch is reported by measuring the flow over weirs that are located at the ends of the seepage collection ditch. The weirs are suitable for measuring variations in gross flow, but the weirs may not be accurate enough for the flow measurements required for very close model calibrations.

The connection of the pond to a buried plant aggregate zone significantly affected the calibration of flow between the measured and computed values. Before 2003 plant aggregate was dumped in the location of the current filter berm and further upstream over the top of fine tailings. The plant aggregate piles were reported to be 10 or more feet high and a total zone thickness based on a bottom elevation around 1,170 feet and top elevation of about 1,200 feet. Around 2003 the filter berm was constructed over the top of the plant aggregate and fine tailings were discharged upstream of the filter berm. The fine tailings flowed around and over the upstream plant aggregate, eventually covering the plant aggregate in 2006. This zone of plant aggregate creates a zone of high-permeability material upstream, under, and downstream of the filter berm. The zone acts as a seepage conduit. In the future the thickness of fine tailings over the upstream plant aggregate will increase until the fine tailings act as a seepage cutoff, thereby reducing the impact of the seepage downstream of the filter berm. The configuration of the plant aggregate under the filter berm is shown on Figure 1.1.

In 1997 Sitka presented calculations for seepage through a revised dam section using a cutoff similar to the existing offset upstream seepage cutoff. The buried zone of plant aggregate in the figures presented show about 10 feet of plant aggregate upstream and under the seepage cutoff. The Sitka (1997) estimates for seepage flow were presented at rates of about 150 gpm for through-dam seepage using the same permeability for the fine tailings and plan aggregate presented in Barr (2009). This estimate also provided for a beach length of 300 feet. In the event of a flood condition where the pond would reach within 10 feet of the crest and remain long enough to reach steady state conditions, the through dam seepage was estimated to be 700 gpm for the entire dam. As stated previously, the dam seepage as reported in September 2006 and measured in the seepage collection ditch was 1,177.3 gpm with a beach length of about 300 feet. In the spring of 2009 the seepage had increased to 1,295 gpm at a pond elevation of 1,207.6 feet. There is a significant discrepancy in the amount of seepage that is being measured in the seepage collection ditch compared to previous analyses. The location and thickness of the buried plant aggregate zone seems to impact the seepage quantities.

Another aspect of the seepage calibration that proved difficult was a preliminary analysis of matching the relief well flow rates. This was not attempted in the final seepage models because only

12 relief wells are distributed across 5,189 feet of dam length. Where relief outlets are exposed, the flow rates have been measured along with the total head. The seepage evaluation reveals that much of the flow present at the toe of the dam is not being captured by the relief wells. Rather, the flow is through subsurface layers and into the seepage collection pond. It is difficult to measure the subsurface quantity of the un-captured flow into the seepage collection pond.

5.1.1.2 Calculated Total Heads vs. Measured Total Heads at Piezometer Locations

In order to check the accuracy of the seepage analysis and the validity of the input parameters, the second step in the calibration process compared the total heads from the SEEP/W model against total heads measured in the field by piezometers. The measured heads were evaluated at the piezometers located along the cross section at Station 28+40 and to some extent 35+00, as shown in Figure 1.1. The monitoring data from 2006 was used in the analysis.

A comparison of the computed and measured heads is shown in Table 5.1.1.2a, which shows that the results are reasonably close except at a few locations. Since 2003 a significant emphasis has been placed on evaluating the piezometers. As a result many piezometers were deactivated because of poor data quality or failure of the system. Three piezometers used in the 2003 analysis have been destroyed or terminated due to malfunction. These piezometers are 3J-P1, 3J-P2, and 3J-P3. A piezometer that was not used in the 2003 analysis, P97-2, was destroyed. Recently added piezometers provide additional data points to compare with computed heads. These locations, shown in Figure 1.1, are P97-1, P97-10A, P97-10B, and P97-10C. The piezometers used in these analyses are generally considered to provide high-quality data. Upgrades to the monitoring program have increased since 2003, and equipment is evaluated and replaced every year as needed.

For this evaluation using revised permeability values, most computed total head values at piezometers within the more permeable layers of glacial till and fine tailings were computed to be within 3 feet of the measured values. The computed head at each of the piezometers located in the lacustrine clay exceeds the observed head by more than 6 feet and, in some cases, by more than 10 feet. Reasonable explanations exist for differences between measured and calculated values at piezometer locations. For example, some of these devices are within the less-permeable clay. Piezometers 3B-P2, 3B-P3, 3F-P1, 3F-P2, 3G-P1, and 3G-P2 were installed in the lacustrine clay. These piezometer values are difficult to match precisely because they are in a soil unit where the low clay permeability results in significant head loss. A relatively small error in the depth or lateral position of the piezometer tip can have a relatively large impact on the measured head as observed in the initial model-development process. Additionally, some of the instrumentation is older. These piezometers may not be reporting accurate data. The result is a more conservative seepage model because the computed head within the model at these piezometers is more than 6 feet higher than the actual measured head.

Many iterations of the seepage model were completed to evaluate the affect of adjusting the clay permeability to match the modeled piezometers and the measured piezometer values. The permeability of the clay was adjusted higher or lower, as was the permeability of the sand and gravel. If the permeability of the clays were changed or permeability of the materials upstream of the clay were altered (fine tailings or plant aggregate), computed heads at other upstream piezometers would change drastically. Upstream piezometers within granular material with fairly well known permeability changed to unrealistic values. It became apparent that the measured and computed total heads at piezometers in the clay such as 3G-P1, 3G-P2, 3B-P1, and 3B-P2 would not match more closely. These piezometers are located in zones that have an impact on the stability of the dam. Therefore, the difference between the computed and measured total heads is a conservative assessment because the computed total heads are greater than those measured.

The piezometers installed within the till foundation, such as such as 3B-P1, had calculated total heads within 3 feet of the measured values. Piezometer P97-1 had a calculated total head exceeding the measured value by about 6 feet. Though 3F-P2 was installed in the lacustrine clay, it was computed to be within 1 foot of the measured total head value. This is important. It is positioned at the toe of the dam, a critical location. A review of the relief wells near piezometer P97-1 indicates that the measured total head is in the range of 1132.77 and 1138.16 during the calibration period. This results in a range in excess calculated pressure within the model of about 4 to 10 feet.

The measured total head at piezometer 3K-P2, which is installed in the fine tailings, appears to be an outlier and may be a malfunctioning piece of equipment. Its tip is only about 7.5 feet higher in elevation than piezometer 3K-P1 (also in the fine tailings), and they are installed at the same plan location. However, piezometer 3K-P2 reports a total head more than 13 feet lower than 3K-P1 and other piezometers installed in the fine tailings/slimes. Thus, this piezometer was not considered for the model calibration.

In summary the piezometer readings and computed total head values are reasonably close for the fine tailings, plant aggregate and glacial till foundation. The computed total head values within the lacustrine clay exceed the measured values by about 12 feet in some instances. In general the computed values for all materials are higher than the measured values, which results in pore-water pressures imported into the slope stability model that are more conservative than the field measurements. The models predict a worse scenario than the piezometers report. This key point should be considered.

The computed piezometer total head values are in excess of the measured total head measurements at locations important to the dam's stability Subsequent stability models will have a level of conservatism built into them based on solely on the seepage assessment. In the future it will be important to evaluate those piezometers and their readings by performing in-situ tests or installing updated piezometers to validate the readings and then recalibrating the seepage models prior to design of subsequent raises.

Table 5.1.1.2b summarizes the revised permeability values used in the analysis based on the model calibration. The values do not differ significantly from those proposed in Table 4.2.4. In the final seepage model the permeabilities of sand and gravel were adjusted to slightly higher values, although the lacustrine clay permeabilities were not changed. Appendix B includes the results of the seepage analysis as SEEP/W output figures with the contours of total heads of the seepage model.

The seepage analysis also predicts pore-water pressures for the slope stability analysis, which can be used to calculate the factor of safety against uplift at the toe of the dam. Based upon calculated pore pressures at the toe of the dam from the seepage model, the factor of safety against uplift for existing conditions is 1.04. This value is generally considered unacceptable but is based on the conservative seepage model where total heads within the glacial till foundations were computed to exceed the measured total heads during monitoring events. The location where the uplift was calculated is also below the toe of the dam within the seepage collection pond where there is minimal overburden. The total head measured at piezometer 97-1 at the time of the calibration period is 1136.4 which relates to a factor of safety of about 1.3. This is considered marginal. A factor of safety against uplift of 1.5 is generally considered acceptable with respect to uplift.

The most recently measured (April 2009) total head from piezometer P97-1 is 1,134.8 results in a factor of safety of 1.41 below the toe of the dam within the seepage pond. This assumes minimal pore pressure dissipation over a horizontal distance of 20 feet from the toe of the slope. If the factor of safety is computed within the slope, the result is a value of 1.95. At piezometer P97-4, which is also located at the toe of the dam further down-station, the factor of safety against uplift is about 1.8. The total heads measured at relief wells R-6 and R-7, near piezometer P-97-1, were reviewed. The computed factors of safety range from about 1.06 to 1.67. The higher safety factors represent a calculation using over burden pressures within the toe of the dam and include plant aggregate cover. The lower factor of safety values represent minimal overburden pressure in the seepage collection pond, which contrasts to the high factors of safety calculated at locations near the relief wells and piezometers that are higher up the slope of the dam.

These ranges in actual factors of safety compared to the computed factor of safety against uplift from the modeled total heads show the model's level of conservatism in predicting the pressures in the till and the lacustrine clay. The model will always predict higher pore pressures along the toe of the dam because the relief wells were not included in the seepage model. Sitka (1998) suggested that as pond levels and the dams rise, uplift at the toe could be a concern. Ongoing measurements of the piezometers and observations should be made to evaluate the potential for uplift.

The numerous relief wells installed in the initial construction of the dams that are currently in place near the toe of the dam provide a stabilizing effect by limiting the total head within the glacial till foundation and lacustrine clay layer and by discharging seepage that cannot be quantified easily in the seepage model. As discussed previously many relief wells are submerged under the seepage collection pond water surface and cannot be located. Therefore flow rates and total head cannot be measured and compared to the seepage models. The relief well design is not known and only preliminary information on a typical layout for a relief well installation is available. It will be necessary to conduct further evaluations using current and possibly future installations of instrumentation and relief wells prior to the next dam raise

5.2 Seepage Analysis under Proposed Conditions

Seepage analyses were also used to compute the seepage forces within the dam at each of the proposed dam crest elevations at 1,230, 1,245, and 1,315 feet. The results of the seepage analyses (SEEP/W output) are included in Appendix B. The analyses were also used to compute the factor of safety against uplift under the proposed concept condition.

The models show that the fine tailings begin to act as a cutoff over the next few dam raises. Currently there is minimal head loss across the fine tailings because of the previously discussed layer of buried plant aggregate under and upstream of the filter berm. Only a relatively thin layer of fine tailings has been deposited over the piles of plant aggregate placed upstream prior to 2003. As the basin and dams rise to elevations 1,230 and 1,245 feet more fine tailings will cover the plant aggregate and start acting as a cutoff at the location of the filter berm. The phreatic line that reflects the increasing head loss for the dam elevations is shown in Figures 5.2 a, b, and c, which were developed from the seepage model output. The figures show the upper pond limit or maximum water level on the left side. The phreatic line shown on the figure depicts the water table within the dam section where the material below the line is saturated and the material above the line is unsaturated. In other words, it represents a line of zero pore-water pressure.

The location of the tailings pond water on the beach also has an impact on the seepage across the dam. As shown in Figures 5.2a, b, and c, the total head within the pond at flood condition was used to evaluate the dams under steady state conditions. The seepage at each of these dam elevations is governed by the location of the pond and when the pond is closer to the seepage cutoff, less head loss occurs prior to passing through the cutoff. When the pond level is such that a beach length of 300 feet is maintained, head loss through the fine tailings occurs and a reduction in seepage will result. However as with the existing conditions model, the buried plant aggregate has an impact on seepage quantities. For the dam elevation of 1,230 feet, the seepage rate is estimated to be about 1,876 gpm however; the actual reported rate from May 2009 is only 1,207 gpm, a conservative difference of about 64 percent. At the ultimate dam elevation the estimated seepage rate is about 5,000 gpm under the flood condition. Assuming the difference between actual and estimated is similar to other analyses, only 2,500 gpm would occur.

The seepage model was also used to estimate the factor of safety against uplift for the proposed conditions, and the results are presented in Table 5.2. These values are considered unacceptable based on the model results. However, observed measurements from the instrumentation indicate that there is a significantly higher safety factor for the existing conditions. A correction factor was calculated to convert the factor of safety against uplift from the model to a value that represents values from actual piezometer data. The correction factor (1.26) consisted of making the assumption that the ratio of the factor of safety for the observed total head (1.31) and the computed total head (1.04) for the existing condition remains constant over time. The proposed factors of safety estimated for the future conditions—as shown on Table 5.2—were adjusted by multiplying the model computed factors of safety by 1.26. The resulting estimated factors of safety are shown in Table 5.2. These adjusted factors of safety are considered marginally acceptable as they are less that 1.5, yet greater than 1.1.

Additional instrumentation along the toe of the dam should be installed to evaluate the pressures that may exist and should be monitored as the dams are raised. If the safety factor decreases to unacceptable values, additional relief wells or plant aggregate buttresses along the toe of the dam may be required. The plant aggregate stockpile would also serve to stabilize the toe of the dam. For instance, a layer of plant aggregate 10 feet thick along the toe of the dam could increase the safety factor to an acceptable level greater than 1.5 based on the computed total head within the model.

5.3 Slope Stability Analysis

The lacustrine clay foundation was found to be a critical component in the stability of the tailings basin in Barr's 2003 analysis and in previous analyses by Sitka and Klohn. The fine tailings are considered a significant unit within the dam and needed to be addressed in these analyses. The Barr (2009) report provided the appropriate design parameters for the stability analyses to evaluate the drained, undrained, and liquefied factors of safety for the dam.

As discussed in previous sections, the modeling procedure included evaluating the dams for both the undrained loading in the USSA and the drained loading in the ESSA. In the analyses both the DSS and the TXC envelopes were used for the lacustrine clay. The mode of failure was evaluated for both the circular failure and block failure. The stability was evaluated at the existing conditions and elevations 1230, 1245, and 1315 feet. Appendix C includes the results of the following stability analyses, which includes the plots of the critical failure surfaces for each scenario.

5.3.1 USSA Analysis

The following sections describe the approach used when performing the USSA analyses for Dam 1. The dams were analyzed for the existing conditions and then for each of the proposed elevations.

5.3.1.1 Existing Geometry Results

The first step in evaluating the stability of the dams was to calculate the factors of safety for the existing condition. This condition assumed a dam elevation of 1,215 feet and the seepage pressures calculated from the existing conditions seepage model. A USSA was performed on the dam section under existing conditions to evaluate the safety factors and the current condition of the dam. The impact of yield strength and liquefied strength of the fine tailings was evaluated on the dam stability as part of the USSA analysis. The liquefied strength analysis is presented in a subsequent section.

Since the dam is relatively low in its current condition, the strength of the tailings had little impact on the overall stability of the dams. The factors of safety for the existing geometry for the analyses completed are presented in Table 5.3.1.1. The lowest factor of safety (1.44) was computed for the USSA analysis for a circular failure surface through the clay foundation. This computed factor of safety is generally independent of the normally consolidated lacustrine clay and fine tailings strengths used in the analysis. The factor of safety was identified as a toe failure, influenced by the strength of the overconsolidated lacustrine clay and the elevated phreatic surface. In the seepage analysis the total heads within the lacustrine clay layers were computed to be greater than 10 feet more than measured total head at some piezometers, yet the total head in the glacial till foundation were computed to be only 6 feet greater than the measured total head at piezometers. The failure surfaces for all the analyses either develop along the glacial till and lacustrine clay boundary or through the glacial till. This indicates that although elevated total heads within the lacustrine clay were computed in the seepage model and used in the stability model, the elevated total heads within lacustrine clay had less impact on the stability than in the glacial till where the modeled total heads compared more closely with instrumentation. The range of computed factors of safety was 1.44 to 2.10 for the USSA analyses. The safety factors are acceptable because they are greater than 1.3.

It should be noted that the current monitoring data indicates the dam is stable. There is no indication that movement is occurring in the inclinometers. These measurements show the dam is at a factor of safety greater than 1.0. If the inclinometers had reported small movements over a period of time, it would be estimated the dams are near a safety factor of 1.0.

5.3.1.2 Proposed Geometry Results

The proposed geometry for the long-term dam construction consists of extending the downstream slope above the seepage collection ditch at an overall slope of 6H:1V to elevation 1,315 feet as shown on Figure 1.1. This concept was presented in Barr 2003. The dam construction that has been completed since 2003 has been in preparation for the future raises. The filter berms—constructed sequentially on top of each other—act as a filter for the fine tailings. The fine tailings perform as a seepage cutoff. Finally, the upstream slope of the seepage collection ditch has been regraded and vegetated for long-term reclamation of the slope. Future raises will be constructed above the reclaimed slope. The dam construction materials will consist of plant aggregate with a filter berm upstream and fine tailings deposited on the beach of the basin. This is consistent with recent practices.

The study evaluated the dam for the proposed conditions for dam raises at elevations 1,230 and 1,245 feet. This allowed the identification of immediate design and stability issues, which must be addressed over the next few years. It also allowed evaluation of the dam at the ultimate elevation of 1,315 feet, where long-term design and construction issues may develop. Table 5.3.1.2 summarizes the results of the limit-equilibrium slope-stability USSA analysis for the proposed Dam 1 geometries in terms of the factor of safety. The evaluation shows that the factors of safety exceed the minimum recommended value for the next two dam raises to elevation 1,245 feet. The minimum value is 1.41, which occurs at elevation 1,245 feet under all load case scenarios for a circular failure. For a block failure, the safety factors range from 1.50 to 2.09.

However, for the ultimate dam configuration at elevation 1,315 feet, the lowest computed factor of safety is 1.27, less than the recommended value of 1.3. This low safety factor was an undrained analysis using the lower-bound clay failure envelope for block-failure mode and yield strength of the fine tailings. This value is only slightly below the minimum recommended value of 1.3 because it is based on the lower-bound strength value for the clay and conservative seepage model. It is conservative in comparison to all the other analyses. It should also be considered only an estimation of the factor of safety. Up to 60 years may pass before the dam reaches elevation 1,315 feet. Many changes may take place in the seepage conditions of the dam, including possible stockpiling of plant aggregate along the toe of the dam for storage and strength-gain in foundation and dam materials. However, these results can be used for long-term planning at the basin. While the value is lower than the recommended value of 1.3, the scenario occurs only at the ultimate dam elevation and it does not account for any possible strength gained over time by consolidation of materials. The remaining USSA factors of safety range from 1.43 to 1.89 for the ultimate dam configuration that uses the fine tailings yield strength. These factors of safety are considered acceptable.

5.3.2 ESSA Analysis

The ESSA analyses consider the long-term design and drained behavior for the tailings dams. The following sections discuss the analyses of the existing and proposed dam configuration.

5.3.2.1 Existing Geometry Results

The results of the ESSA analyses for the existing conditions are shown in Table 5.3.2.1. For the ESSA analysis the lowest computed factor of safety was 1.59 using a block failure mode and the DSS lower-bound strength envelope using drained strength parameters. The safety factors for all of the analyses performed ranged from 1.59 to 2.46. These are considered acceptable.

5.3.2.2 Proposed Geometry Results

Table 5.3.2.2 shows the results for the ESSA analysis. For the ESSA analysis the lowest computed factor of safety was 1.51 for a block failure mode at crest elevation 1,315 feet, and using the lower-bound DSS lacustrine clay strength in the analysis. For ESSA analyses the computed factors of safety were 1.51 to 2.34. This meets the minimum factor of safety of 1.5 up to elevation 1,315 feet.

5.3.3 Liquefied Strength Analysis

As discussed previously, it was assumed for this report that liquefaction would be triggered. Thus, a flow liquefaction stability analysis of the dam should be performed. Therefore, the liquefaction analyses used both the existing and proposed conditions similar to previous analyses. The liquefied strength analysis used a methodology similar to the USSA analysis. Instead of a USSR of 0.2 for the fine tailings, the liquefied strength USSR of 0.1 was used. The clay strengths were adjusted as in previous analyses. The following sections present the results.

5.3.3.1 Existing Geometry Results

The liquefied strength analysis was performed for the existing conditions while varying the clay strengths between the DSS and TXC average and lower-bound values. The liquefied strength was applied to the entire fine tailings zone within the dam resulting in a conservative application of the strength. In reality, not all zones within a liquefiable mass are reduced to the liquefied strength at one time. However, it is difficult to apply the strength in a manner that may occur in the field. Therefore, common practice is to apply the strength value to the entire mass.

Table 5.3.3.1 presents analyses for the existing conditions. The results show that, in the current configuration, the buried fine tailings deposit has little impact on the stability of the dam. The stability is controlled more by the strength of the foundation clays. Therefore, the results of the analyses are similar to those presented for the USSA yield strength in section 5.3.3.1. The factors of safety range from 1.44 to 2.10 and exceed the minimum recommended value of 1.05.

5.3.3.2 Proposed Geometry Results

For the proposed conditions analyses, the models were similar to those described in section 5.3.1.2. The strength of the fine tailings was reduced to the liquefied strength. Table 5.3.3.2 presents the results of the analyses and shows that the factors of safety range from 1.19 to 2.09, thereby exceeding the minimum recommended value of 1.05. For the ultimate dam elevation the minimum factor of safety representing the lower-bound DSS strength in a block failure mode is 1.19. This is considered a lower-bound value since the model uses elevated pore-water pressures, liquefied strength, and does not consider any strength gain over time.

5.4 Summary of Dam 1 Evaluation

The computed factors of safety for the existing condition elevation of 1,215 feet are adequate for Dam 1. As evidenced by the monitoring data, the dam is currently stable. As the dams are raised, the safety factors generally decrease due to the change in load on the foundation. With the exception of one case (discussed previously: the ultimate dam elevation where the safety factor was 1.27, which is marginally below the recommended value of 1.3), the factors of safety meet the minimum recommended values. An evaluation was conducted using elevated pore pressures and lower-bound strength values for both the drained and undrained cases. These analyses should be used for long-range planning. Updated analyses will be necessary as changes occur in the basin over the next 60 years. Appendix C presents the results of the stability analyses, which includes the plot of the critical failure surface for each scenario evaluated.

6.0 Dam 2 Evaluation

Dam 2 is located on the northern end of the tailings basin. Figure 1.2 shows a cross section of Dam 2 in schematic form. At Dam 2 the clay cutoff was constructed as a central core in the starter dam. Plant aggregate comprises the fill material placed on natural ground to the existing dam elevation and extending 500 to 600 feet upstream of the starter dam. After completion of the plant aggregate placement, fine tailings were discharged into the basin creating beaches.

Beginning in 2003 the offset upstream approach used for Dam 1 was also used for Dam 2. A filter berm was constructed about 800 feet upstream of the starter dam. Prior to constructing the filter berm, the mode of dam construction was to discharge tailings into the basin, creating beaches. In this area, however, 20 feet of plant aggregate was used to cover the previously deposited 30 feet of fine tailings deposits. The area downstream of the filter berm is raised using only plant aggregate. The proposed downstream dam slope for Dam 2 is 6H: 1V for the ultimate height of the dam at elevation 1,315 feet. Additional details of Dam 2 are shown in sheets G-06 through G-09 (Appendix A).

There is a peat deposit overlying the lacustrine clay and glacial till within about one half of the central upstream portion of the dam. The peat is 3 to 5 feet thick, compressed from its original 10-foot thickness. Previous investigations identified an alluvial channel cut into the glacial till in the center of the dam site near the middle of the dam.

In 1997 a toe berm constructed of plant aggregate was placed along the downstream toe of Dam 2 at the lowest natural ground, where the dam section will be highest. This toe berm is 2,000 feet long from station 27+00 to station 47+00. The toe berm increased dam stability by providing a means for drainage of seepage and providing additional weight along the toe of the dam.

Figure 6.0 shows a schematic of the general groundwater flow from the tailings. This diagram show how the seepage cutoff is utilized and how the groundwater flows through the dam cross section.

6.1 Seepage Analysis under Existing Conditions

To calibrate the model with the recommended design values proposed in Barr (2009), a seepage analysis was performed under the existing conditions at the basin for Dam 2. Similar to the Dam 1 calibration, the process was used in which the computed seepage in the seepage collection ditch and the pressures at each of the piezometers were compared to measured values. The appropriate permeability of each unit within the model stratigraphy was determined based on how well the computed values matched measured values. The following sections describe the process of model development and evaluation used for Dam 2.

6.1.1 Comparison with Field Performance

The seepage models for Dam 2 were evaluated by comparing the calculated conditions to the observed conditions at the dam. Permeabilities for four of the material types were altered from those presented in Table 4.2.4 in order to match measured piezometer levels and flow rates in the seepage channel and at the toe. These materials were the foundation till, normally consolidated lacustrine clay, overconsolidated lacustrine clay, and the sand and gravel from the starter dam construction. A review of the clays at the tailings facility indicated that anisotropy was more pronounced in the clays near Dam 1 than Dam 2. Anisotropy was not, therefore, used in the Dam 2 model. Because anisotropy was variable, it was simpler to adjust the permeability in the model to correlate the computed heads with the measured heads at piezometers. This resulted in a "composite" permeability in the model. The following sections present the details of the calibration procedure.

6.1.1.1 Calculated Seepage vs. Measured Flow

Seepage collection ditch measurements from September 25, 2006, indicated that flow rate at the weirs was about 775 gpm. The flow rate at Dam 2 was about 775 gpm with a seepage collection ditch length of about 3,700 feet. The permeability values shown in Table 6.1.1.1 yield a calculated flow rate of about 760 gpm, or a difference from field measurements of about two percent. This is considered an acceptable match due to variability of stratigraphy, expected ranges in permeabilities in the dam cross section over the entire length of the seepage collection ditch, and impacts due to possible precipitation events.

The highly variable nature of precipitation on the plant aggregate surface and infiltration into the dam could result in variable observed seepage at the weirs. Additionally, the seepage is reported by measurements of flow over weirs located at the ends of the seepage collection ditch. This may not be entirely representative of the seepage that flows into the ditch because of the potential seepage through the glacial till cutoff. For instance, the seepage collection ditches at Dam 1 collect significantly more seepage, because the ditches were constructed almost the entire length of the dam. At Dam 2, the seepage collection ditch is much shorter and less seepage per foot of total dam length is observed.

The weirs may not be accurate enough for flow measurements required for very close calibrations, although the weirs are suitable for measuring variations in gross flow. Also as the pond rises the beach length decreases and observed seepage increases. This is what occurred in 2008 when the pond level rose encroaching on an area of the beach that had not been raised with tailings discharge in awhile. The seepage increased up to 1,250 gpm until additional tailings were discharged onto the beach effectively moving the pond out from the dam crest.

As with the Dam 1 analysis, one of the most significant features that affected the calibration of flow between the measured and computed values was the connection of the pond to the plant aggregate. Previous to 2003, plant aggregate was dumped in the location of the current filter berm and further upstream over the top of fine tailings. The plant aggregate piles were 10 or more feet high. Around 2003, the filter berm was constructed over the top of the plant aggregate and fine tailings were discharged upstream of the filter berm. The fine tailings flowed around and over the upstream plant aggregate. The tailings covered the plant aggregate by 2006. This zone of plant aggregate creates a zone of high permeability material upstream, under, and downstream of the filter berm. This zone acts as a seepage conduit. In the future the fine tailing thickness over the upstream plant aggregate will increase and will act as a seepage cutoff, thereby reducing the impact of the seepage downstream of the filter berm. A schematic of the dam cross section showing the plant aggregate layer is shown in Figure 1.2.

Another aspect of the seepage calibration that proved difficult was matching the relief well flow rates. This was not attempted in the final seepage models. Only a few relief wells are distributed across the entire dam length. Some relief wells are flowing and others have not been located. Seepage evaluation suggests that much of the flow present at the toe of the dam appears not to be captured by the relief wells. Rather, the flow is through subsurface layers and into the seepage collection pond. It is difficult to measure this subsurface quantity of the uncaptured flow into the seepage collection pond.

6.1.1.2 Calculated Total Heads vs. Measured Total Heads at Piezometer Locations

The total heads from the SEEP/W model, using permeability values in Table 6.1.1.1, were compared against those measured in the field to check the accuracy of the seepage analysis and proper calibration of the model. The adjustments in the permeability values resulted in close matches in the final calibrated model between the computed and measured heads at each of the piezometer locations. As with Dam 1, piezometer readings used in the analysis were collected in September 2006.

Table 6.1.1.2 shows that the computed and measured total heads at most of the piezometer tip locations are reasonably close to each other as a result of the change in permeability values for this analysis. Most piezometers within the model were computed within about three feet of the measured values with the exception of three locations. Piezometers 3H-P1, 3H-P2, and 97-19B were installed in the lacustrine clay. Precisely matching field measurement is difficult. The glacial till cutoff is a unit in which significant head loss occurs due to low permeability. These piezometers show a difference between the measured and calculated total head of about 12 feet. At piezometer P97-19B, the pressures are in excess of the actual reading. At piezometers 3H-P1 and 3H-P2, the calculated values are about 12 feet less than the measured values. As previously discussed, the differences in pressure may be attributed to a relatively small error in the position of the piezometer tip that can have a relatively large impact on the measured head. Piezometers 3E-P1 and 3E-P2, installed within the lacustrine clay, were within 3 feet of the measured values and are considered a good match. This is important because the piezometers are positioned at the toe of the dam, a critical location in terms of uplift potential.

The discrepancy in the piezometer readings within the clay may also be caused by equipment malfunction. These pneumatic piezometers are more than 10 years old; have been exposed to the elements; and possibly were damaged as the dams were raised. Ongoing equipment evaluation is occurring so that only working piezometers are used in design and evaluation. The piezometers with significant discrepancies will be evaluated further to determine if they should be replaced. Finally, the adjustment to the permeability values in the clay is justified due to location. Dam 2 is distant from Dam 1, where the majority of the laboratory testing had been performed in the past. Klohn had reported in 1976 that a laboratory permeability range of $3x10^{-7}$ to $7x10^{-6}$ cm/sec may be appropriate, while other data suggest values may be less, near $2.3x10^{-8}$ cm/sec. It is apparent that variability exists in this clay deposit. Values of higher permeability were used in the Dam 2 model.

In summary the piezometers within the fine tailings, glacial till foundation, filter, and plant aggregate match the computed values in the model within about three feet and can be considered reasonably close. The piezometers within the lacustrine clay, in most instances match within about 2.8 feet except at piezometer 3H-P1 and 3H-P2 where the computed values were greater than 10 feet lower than measured values. For the locations where the computed and measured values were close, the model reported values are higher than measured piezometer values. This results in pore-water pressures that are imported into the slope stability model to be more conservative than field measurements. The final permeability values used in the model development and presented in Table 6.1.1.1 resulted in a reasonably accurate match between measured and computed head at Dam 2.

The seepage analysis also predicts pore-water pressures for the slope stability analysis, which can be used to calculate the factor of safety against uplift at the toe of the dam. Based upon calculated pore-water pressures at the toe of the dam from the seepage model, the factor of safety against uplift for existing conditions is 1.48. This value is generally considered acceptable because it is based on the conservative seepage model where total heads within the glacial till foundations were computed to exceed the measured total heads during monitoring events.

Using the current measured total heads computed from piezometers P97-12, P97-14, and P97-16, the factor of safety is greater than 2.0, which is considered acceptable. This shows the model's level of conservatism due to the pressures modeled in the till and the lacustrine clay and not observed in the piezometers. The toe berm constructed in 1997 is providing stability and resistance to uplift, as projected in the design.

6.2 Seepage Analysis under Proposed Conditions

Seepage analyses were also used to compute the seepage forces within the dam at each of the proposed dam crest elevations at 1,230, 1,245, and 1,315 feet. The results of the seepage analysis (SEEP/W output) are included in Appendix B. The analyses were also used to compute the factor of safety against uplift under the proposed concept condition.

The models show that the fine tailings begin to act as a cutoff over the next few dam raises, as was expected. There currently is minimal head loss due to fine tailings, because of the layer of plant aggregate under and upstream of the filter berm. Only a relatively thin layer of fine tailings has been deposited over the piles of plant aggregate that were placed upstream before 2003. As the basin and dams rise to elevations 1,230 and 1,245 feet more fine tailings will cover the plant aggregate and start acting as a cutoff at the location of the filter berm. The buried plant aggregate layer has an impact on the seepage as well as the location of the pond on the beach. The phreatic line that reflects the increasing head-loss for the dam elevations evaluated is shown on Figures 6.2 a, b, and c, which were developed from the seepage model output. The monitoring data in 2009 show that the seepage rate is about 605 gpm but since 2007 has ranged from 458 to 1,253 gpm for Dam 2. The dam is currently at elevation 1,230 feet. The range of seepage rates compare well with the calculated seepage rate of about 1,130 gpm from the model.

The seepage model was also used to estimate the factor of safety against uplift for the proposed conditions and the results are presented in Table 6.2. As discussed for the existing conditions, these values are considered acceptable. They are near the acceptable value of 1.5, based on the very conservative seepage model calculations. This value is considered acceptable.

Monitoring of the piezometers should continue in order to monitor uplift pressures over the life of the facility. Additional instrumentation along the toe of the dam could be installed to evaluate the pressures that may exist and should be monitored as the dams rise. Furthermore, if the pressures increase enough so that the factor of safety drops below 1.5, mitigation methods such as additional relief wells, buttresses, or drains should be developed.

6.3 Slope Stability Analysis

During the 2003 analysis by Barr and previous analyses by Sitka and Klohn, the lacustrine clay foundation was found to be a critical component in the stability of the tailings basin. Although significant enough to merit analysis, the fine tailings had less influence on the stability of the dam than originally thought. As discussed in previous sections of this report, the modeling procedure included evaluating the dams for both the undrained loading in the USSA and the drained loading in the ESSA. In the analyses, both the DSS and the TXC envelopes were used for the lacustrine clay. The mode of failure was evaluated for both the circular failure and block failure. The stability was evaluated at the existing conditions and elevations 1230, 1245, and 1315 feet. Appendix C includes the results of the following stability analyses, which includes the plots of the critical failure surfaces for each scenario.

In 1996 Sitka prepared a design report for a toe berm to stabilize the dam. Sitka described two toe berm design scenarios; one to elevation 1,166 feet and another to elevation 1,178 feet. Currently the dam toe berm is near elevation 1,170 feet. It appears that the full height of the buttress was not constructed. Based on the Sitka analyses, the projected factor of safety for the downstream portion of the dam once the pond water level exceeds the elevation of the glacial till cutoff is between 1.54 and 1.87. This evaluation by Sitka projected uplift forces because of increased pore-water pressures below and within the lacustrine clay along the toe of the dam. The following sections of the report discuss the computed factors of safety for the dam at the existing and proposed elevations.

6.3.1 USSA Analysis

The following sections describe the approach used when performing the USSA analyses for Dam 2. First, the dams were analyzed for the existing conditions and then for each proposed elevation.

6.3.1.1 Existing Geometry Results

The first step in evaluating the stability of the dams was to calculate the factors of safety for the existing condition. This condition assumed a dam elevation of 1,215 feet and the seepage pressures calculated from the existing conditions seepage model. It should be noted that the current monitoring data indicates the dam is stable. There is no indication that movement is occurring in the inclinometers.

A USSA was performed on the dam section under the existing conditions to evaluate the safety factors and the current condition of the dam. As part of the USSA analysis, the impact of the yield strength and liquefied strength of the fine tailings was evaluated on the dam stability. The liquefied strength analysis is presented in a subsequent section.

Since the dam is relatively low in its current condition, the strength of the tailings had little impact on the overall stability of the dams. The factors of safety for the existing geometry are presented in Table 6.3.1.1 for the analyses completed. The lowest factor of safety (1.71) was computed for the USSA analysis for a circular and block failure surface through the clay foundation. The total heads within the lacustrine clay layers were computed greater than 10 feet at some piezometers, yet the total heads in the glacial till foundation were computed to be in excess of only 2 to 3 feet of the piezometers within the seepage model. The failure surfaces for all the analyses either develop along the glacial till and lacustrine clay boundary or through the glacial till. This indicates that although elevated total heads within the lacustrine clay were computed in the seepage model and used in the stability model, the total heads within lacustrine clay had less impact on the stability than the glacial till where the modeled total heads compared more closely with instrumentation. The range of computed factors of safety was 1.71 to 2.29 for the USSA analyses. The safety factors are acceptable since they are greater than 1.3.

6.3.1.2 Proposed Geometry Results

The proposed geometry for the long-term dam construction consists of extending the slope above the seepage collection ditch at an overall slope of 6H:1V to elevation 1,315 feet as shown on Figure 1.2. This concept was presented in Barr (2003) and the dam construction completed since 2003 has been in preparation for the future raises. The design also incorporates the Sitka (1996) toe berm as designed and shown in the drawings. The filter berms have been constructed sequentially on top of each other to act as a filter for the fine tailings. The fine tailings act as a seepage cutoff. Finally the upstream slope of the seepage collection ditch has been regraded and vegetated for long-term reclamation of the slope. Future raises will be constructed above the reclaimed slope. Dam construction materials will consist of plant aggregate with a filter berm upstream and fine tailings seepage cutoff deposited on the beach of the basin. These materials are consistent with recent practices.

The study evaluated the dam for the proposed conditions for dam raises at elevations 1,230 and 1,245 feet, in order to identify any immediate design and stability issues that must be addressed over the next few years and to learn the condition of the dam at the ultimate elevation of 1,315 feet, where long-term design and construction issues may develop. No immediate design and stability issues were identified as a result of this evaluation. Table 6.3.1.2 summarizes the results of the limit-equilibrium slope-stability USSA analysis for the proposed Dam 2 geometries in terms of the factor of safety. The evaluation shows that for the next two dam raises (to elevation 1,245 feet) the factors of safety are adequate and meet the minimum recommended values. The minimum value is 1.70, which occurs at elevation 1,245 feet with the lower-bound DSS strength and a block failure mode.

For the ultimate dam configuration at elevation 1,315 feet, the lowest factor of safety of 1.46 was computed for the lower-bound-DSS strength and block failure mode. This minimum factor of safety exceeds the minimum recommended factor of safety of 1.3.

6.3.2 ESSA Analysis

The ESSA analyses consider the long-term design and drained behavior for the tailings dams. The following sections discuss the analyses of the existing and proposed dam configuration.

6.3.2.1 Existing Geometry Results

The results of the ESSA analyses for the existing conditions are shown in Table 6.3.2.1. For the ESSA analysis, the lowest computed factor of safety was 2.03 using drained strength parameters, a block failure mode, and the DSS lower-bound strength envelope. The safety factors for the analyses ranged from 2.03 to 3.33 and are considered acceptable.

6.3.2.2 Proposed Geometry Results

Table 6.3.2.2 shows the results for the ESSA analysis for the proposed geometry. For the ESSA analysis, the lowest computed factor of safety was 2.01 for a block failure mode at crest elevation 1,315 feet, and using the lower-bound DSS lacustrine clay strength in the analysis. The factors of safety for the analyses ranged from 2.01 to 3.34 and are considered acceptable.

6.3.3 Liquefied Strength Analysis

As discussed previously, it was assumed for this report that liquefaction would be triggered, and thus a flow liquefaction stability analysis of the dam should be performed. Therefore the liquefaction analyses used both the existing and proposed conditions similar to previous analyses. The liquefied strength analysis used a process similar to the USSA analysis. However, instead of a USSR of 0.2

for the fine tailings, the liquefied strength USSR of 0.1 was used. The USSA clay strengths were adjusted as in previous analyses. The following sections present the results.

6.3.3.1 Existing Geometry Results

The liquefied strength analysis was performed for the existing conditions while varying the clay strengths between the DSS and TXC average and lower-bound values. The liquefied strength was applied to the dam's entire fine tailings zone, which resulted in a conservative application of the strength. Table 6.3.3.1 presents the results of the analyses for the existing conditions. The results show that in the current configuration, the buried fine tailings deposit has little impact on the stability of the dam. The stability is controlled more by the strength of the foundation clays. Therefore, the results of the analyses are similar to those presented for the USSA yield strength in section 6.3.1.2. The factors of safety range from 1.70 to 2.29. The factors exceed the minimum recommended value of 1.05.

6.3.3.2 Proposed Geometry Results

For the proposed conditions analyses the strength of the fine tailings was reduced to the liquefied strength. Table 6.3.3.2 presents the results of the analyses and shows that the factors of safety range from 1.31 to 2.32. The factors of safety exceed the minimum recommended value of 1.05. For the ultimate dam elevation the minimum factor of safety representing the lower bound DSS strength in a block failure mode is 1.31. This is considered a lower-bound value, since the model uses elevated pore-water pressures and liquefied strength. The model does not consider any gain of strength over time.

6.4 Summary of Dam 2 Evaluation

The computed factors of safety for the existing conditions are adequate for Dam 2. This evaluation was conducted using a conservative approach with elevated pore pressures within and below the clay and lower bound strength values for both the drained and undrained cases. As the dams are raised, the safety factors generally decrease due to the change in load on the clay foundation and changes in pore-water pressure. These analyses should be used for long-range planning. Updated analyses will be necessary as changes occur in the basin over the next 60 years. Monitoring of the piezometers, including the addition of targeted instrumentation within the clay layers and just below the clay in the glacial till, should continue to verify that the modeling assumptions used for this dam are valid.

7.0 Dam 5 Evaluation

Dam 5 is located on the east side of the tailings basin north of the Reclaim Pond (see Figure 1.3). It was originally constructed as two dams, Dam 5A and Dam 5B. The dams were joined as they were raised. The dam is constructed over a layer of clay on the south end, a rock knob in the middle, and a rock foundation on the north end. The northern rock foundation was improved using blanket grouting during the initial construction. The middle rock knob was blanketed in filter tailings as the dams were raised. A central glacial till cutoff was used in the initial design, and this has been carried over to more recent raises. The dam uses the glacial till cutoff as shown in Figure 1.3. The soft clay and organic deposit have been removed under the current dam cross section and filter tailings have been placed above the downstream portion of the clay foundation. A plant aggregate drain has been constructed above the filter tailings along the entire downstream portion of the dam. Additional details are shown on sheets G-11 through G-13 (Appendix A). The details of the constructed dam include the different types of plant aggregate used for the dam raise. For instance select coarse aggregate is the well blended plant aggregate material consisting of all the belt filter tailings and coarse tailings. The plant aggregate zones are the areas where any plant aggregate-type material with or without the filter tailings is used for construction. The filter zones are the belt filter tailings otherwise known as filter tailings that are separated from the plant aggregate during processing.

In 2005 a major dam construction point brought the dam crest to elevation 1,215 feet. Prior to design and construction seepage water was leaking along the interface of the north side of the rock knob and the glacial till cutoff. In other areas, water was seeping over the glacial till cutoff. To address these issues and provide a stable 6H:1V downstream slope, a new dam design was developed and constructed in 2005. The sloping glacial till cutoff was changed to a vertical cutoff and the dam was raised using centerline construction. In 2008 the cutoff of the dam was raised to elevation 1,225 feet. Future dam raises will be constructed using the centerline method to the ultimate dam elevation of 1,315 feet. Figure 7.0 shows a schematic of the general groundwater flow from the tailings. This diagram show how the seepage cutoff is utilized and how the groundwater flows through the dam cross section. In this area an unidentified total thickness of clay overlies bedrock below the dam as described in previous reports. As a result of the thin deposit of clay, blanket grouting had been used on the north end of the dam to reduce seepage. Blanket grouting had not been used on the south end of the dam. Based on the instrumentation information it appears that groundwater general follows the schematic diagram. Further instrumentation will be installed to evaluate the groundwater conditions in the future.

7.1 Seepage Analysis under Existing Conditions

The dam stratigraphy and seepage model were developed based on the conditions encountered in 2004 and are also shown on Sheet G-11 (Appendix A) for section 14+00. The dam crest elevation was 1,215 feet. This section also shows the dam configuration for the 2008 dam raise. This was necessary because some piezometers have been inoperable since 2004. Additionally, new piezometers that were installed in subsequent years reported measured total heads that did not correspond with model-predicted levels within the dam. These piezometers eventually failed as well and plans have been made to update the instrumentation at the dam.

The permeability values for most of the material types at Dam 5 were kept fixed during the analysis because they were based on laboratory and field data. The permeability values are presented in Table 7.1.1. The permeability of the bedrock and glacial-till cutoff were altered in order to match measured piezometer levels. Unlike Dams 1 and 2, Dam 5 has bedrock near the foundation that appears to have an influence on the overall seepage of the region. As previously discussed, foundation grouting was used on the north end of the dam to limit future seepage. At this location anisotropy was used in the analysis for two materials: foundation till and normally consolidated lacustrine clay.

The dam cross section that was used in the analysis is located on the southern portion of the alignment. This cross section is considered the critical section because it is the area that will eventually have the highest elevation and greatest fill thickness. This dam section would tend to fail into the seepage collection pond if instability were to occur. Finally, this dam section is located in an area that may not have significant upstream construction fill placement in the future. It generally abuts a deeper portion of the tailings pond. Unlike the northern portion of the dam alignment where the railroad grade, material stockpiles, and splitter dike abut the dam, in the future this portion of the dam could have the tailings pond water directly against the plant aggregate without an upstream seepage cutoff. Appendix B includes the results of the seepage analysis performed during model creation and calibration. SEEP/W output figures with the contours of total heads of the seepage model are included in the appendix.

Based on the calculated seepage pressures, the factor of safety for uplift under the existing conditions is 1.21. This matches the observed conditions of possible seepage percolation observed at the toe of the dam when reviewed during a previous dam inspection in 2003. Sometimes small boils can result from pond pore pressures generated by increased loading and resulting pore pressures in the foundation caused by plant aggregate placed on the crest or face of the dam or by seepage induced by the rise in a tailings pond. Latent pore pressures from rapid dewatering when the pond downstream of the dam was pumped out may have contributed to transient excess pore pressures. However the seepage analysis was performed assuming steady-state seepage as with analyses at the other dams. This factor of safety of 1.21 is considered to be below the typical accepted minimum value of 1.5. As part of the revised dam construction plan in 2004 and 2008, a filter and drain layer were incorporated into the design throughout the constructed toe area. This effectively increased the factor of safety to more than 1.5 in the areas where the seepage was observed.

The location at which uplift pressures and factors of safety were computed was directly beneath the toe of the plant aggregate portion of the dam for successive raises and at the bottom of the lacustrine clay. This point was selected because a significant amount of head-loss occurs across the lacustrine clay, which provides a conservative factor of safety against uplift.

7.1.1 Comparison with Field Performance

No seepage-monitoring weirs or relief wells are located on this dam, so the field performance is evaluated using piezometers. Total heads from the SEEP/W model (using permeability values in Table 7.1.1 were compared against those measured in the field to check the accuracy of the seepage analysis. The measured heads correspond to piezometers located along the cross section at Station 14+00 as shown on Sheet G-11 (Appendix A). Piezometer readings used in the analysis were collected in October 2004, as described above. Table 7.1.2 shows the computed and measured heads are within 0.5 feet and are considered an acceptable match.

7.2 Seepage Analysis under Proposed Conditions

The seepage analysis of the proposed conditions was used to compute the factors of safety against uplift under the proposed condition using low and high toe pond elevations. Figures 7.2a, b, c, d, and e show the dam configuration for each raise, and the results of the seepage analysis (SEEP/W output) are included in Appendix B.

As discussed previously the initial computed factors of safety against uplift at the toe were considered inadequate. It was apparent that a modification to the dam would be required to increase the factors of safety for uplift. The proposed solution was a continuation of the graded drain and filter across the entire seepage collection pond and future area of toe construction of the dam. This drain and filter will also be the foundation of subsequent raises and allow construction traffic to access the entire dam footprint over the remaining years of operation. A seepage analysis was performed on the cross section using the foundation drain, and the safety factors with respect to uplift were computed. The computed factors of safety against uplift at the toe of the dam (see Table 7.2) for a crest elevation of 1,230 feet for the low and high toe pond elevations are 1.24 and 1.27, respectively. For a crest elevation of 1,245 feet, the factors of safety are 1.23 and 1.25 for the low and high toe pond elevations, respectively. For the 1,315 feet crest elevation, the plant aggregate abuts the foundation till on the east edge of the toe pond, so pressurized layers are not present. Consequently, uplift factors of safety were not computed. The safety factors are slightly higher than in the existing conditions scenario, but are less than 1.5, based on the computed total heads. Installation of new instrumentation and ongoing monitoring should continue to evaluate the actual factor of safety for uplift along the dam toe based on observational data The results of the revised seepage analysis (SEEP/W output) are included in Appendix B.

7.3 Slope Stability Analysis

Dam 5 models were developed using available information to predict the factors of safety for stability. The proposed conditions are an extension of the existing-condition geometry of using 6H:1V downstream slopes and continuing the glacial-till cutoff in a vertical manner for the remainder of the dam raises. The future configuration on the upstream portion of the dam has not been defined in detail for this dam and therefore some assumptions were made regarding the upstream slope and the location of the tailings pond at the cross section analyzed.

At Dam 5 the stability of the dam at elevation 1,215 feet was studied during the design phase in 2004 and presented in a previous report to NSM. For this study the existing conditions were not revisited. Similar to the analyses for the other dams, only the proposed conditions at elevations 1,230, 1,245, and 1,315 feet were evaluated. Fine tailings are not located within the dam cross section and therefore liquefaction analyses are not required.

7.3.1 Existing Geometry

The existing geometry presented in Figure 1.3 was used for the stability analyses. One major impact to the stability of the dam is the location of the seepage-collection pond at the toe of the dam. Up to the last dam raise, the dam is designed so that, at each raise, sequential excavation of the organic deposit in the bottom of the pond along the toe was completed to accommodate the new dam toe. The area is backfilled with filter sand, and then covered with a plant aggregate drain. When the next dam raise occurs, the same process will be repeated.

Over time the seepage-collection pond fills with seepage from the tailings pond, precipitation, and runoff from the dam and Bear Lake. The water in the pond must be pumped down so the water does not flow back into Bear Lake. The pumping system currently moves the water into the Reclaim Pond. The pond water is pumped to reduce the water volume several times per year and sometimes at a rapid rate. These changes in pond level affect the pore-water pressure regime in the foundation clays. If the pond level is reduced rapidly after being maintained at a high level for a period of time, rapid drawdown conditions could occur, thereby reducing the strength of the clay. This means that the USSA analysis will likely govern the stability of the dam. This impacts the stability of the dam.

Instrumentation on this dam section includes vibrating wire piezometers and inclinometers. The instrumentation has been problematic. Devices become inoperable due to damage from construction traffic or other reasons. The inclinometers have historically not shown movement until last year, when a slight shift in one location was observed that did not relate to construction or other changes in field conditions. Increased monitoring when the device was accessible indicated that further movement had not occurred, although a crack was observed in the slope of the dam this year. The inclinometer did not perceive movement from the crack formation. The crack was likely caused by the rapid dewatering of the pond to provide additional water storage and access to the monitoring equipment. The slope has since been regraded. The following sections discuss the stability of the dam.

7.3.2 Proposed Geometry

Preliminary analyses using the revised strength parameters described in Barr (2009) indicated small toe failures may occur at the dam if the filter and drain are constructed as previously planned throughout the existing seepage collection pond. Although toe failures do not affect the stability of the entire dam, the toes failures need to be repaired on an ongoing basis. Therefore the proposed conditions include the previously designed filter and plant aggregate toe drain features constructed to the ultimate dam footprint prior to the next dam raise. The construction requires that the organic soils found outside of the current dam toe and in the bottom of the seepage collection pond are excavated along the toe of the existing dam to the proposed toe of the ultimate dam. The excavation will be backfilled with a 5-foot-thick graded drain system of filter tailings and then 5 feet of select plant aggregate (filter tailings removed at the plant). The drain provides two benefits. It is a means of draining the clay foundation and preventing piping through the foundation with a graded filter. It also provides a buttressing effect along the toe of the dam for uplift and sliding resistance.

The dams were analyzed for the future conditions at elevations 1230, 1245, and 1315 feet. At these elevations, there are two possible scenarios that could also impact the stability of the dam and are discussed on how they affect the calculated factors of safety. First, the strength of the clay foundation could be different from the clays sampled and tested at Dams 1 and 2. The data shown in Figures 4.3.2.3a and 4.3.2.3c indicate that one sample obtained in 2004 for design of the dams had a lower plasticity index, which results in different behavior than the remaining samples at Dams 1 and 2. However this is only one sample obtained at one location in the area. This sample may also not be representative of all the clay at Dam 5. During the Klohn design process in the 1970s, the same clay strength was recommended and used for all the dams, indicating that Klohn did not find a significant variation in strength. Second, the pore pressure readings could be invalid due to equipment malfunction, leading to discrepancies in actual pore-water pressures in the clay foundation. Some instruments have become inoperable over the years. The data is suspect to a certain extent. Improvements have been made to the application of new instrumentation, including inclinometers. The following sections provide a discussion of the analyses for the proposed conditions.

7.3.2.1 USSA Analysis

The results of the analyses are provided in Table 7.3.2.1 for the USSA analyses. The results show that extending the toe drain and filter blanket now as opposed to during the next dam raise leads to factors of safety greater than the minimum recommended value of 1.3 The safety factors are within the acceptable range for the USSA analysis according to the design parameters presented in Barr (2009). The minimum factor of safety for the USSA analysis is 1.43. This occurs at elevation 1,230 when the pond along the toe is pumped down. If the upper-bound strength values shown in Figure 4.3.2.3a were used, the factors of safety would exceed those listed. Appendix C includes the results of the stability analysis, including the plot of the critical failure surface.

7.3.2.2 ESSA Analysis

The results of the ESSA analyses are provided in Table 7.3.2.2. The results show that, using the design parameters presented in Barr (2009), the factors of safety exceed the minimum recommended values for an ESSA analysis. The minimum factor of safety for the ESSA analysis is 1.99. It occurs at elevation 1,230 when the pond along the toe is pumped down using the lower bound DSS strength and block failure mode. If the upper-bound strength values shown in Figure 4.3.2.3a were used, the factors of safety would exceed those listed. Appendix C includes the results of the stability analysis, which includes the plot of the critical failure surface.

7.4 Summary of Dam 5 Evaluation

An evaluation of Dam 5 that reviewed the seepage and slope stability to determine the factors of safety under various conditions was completed. For future raises using the filter and drain configuration over the entire plan area of the proposed dam, the factors of safety will be acceptable. This is based on design parameters presented in Barr (2009), and these parameters are lower strength than the single test result in the Dam 5 area and the circular failure mode. Since the foundation clay layer is thin compared to the volume of plant aggregate and other much stronger materials within the dam section, the failure mode will likely take the form of a block failure and DSS strengths will govern. Instrumentation has been problematic on this dam, more so than other dams, which leads to questions on validity of the limited piezometer data as ongoing monitoring review is performed. The inclinometers have historically not indicated movement until last year at one monitoring event. A crack was observed in the dam face this year but the movement was not observed in the inclinometer. Increased surveillance is occurring and plans have been made to update the piezometers with devices from an alternate manufacturer.

8.0 Conclusions and Recommendations

8.1 Conclusions

An evaluation of Dams 1, 2, and 5 at the NSM Milepost 7 tailings basin was performed to validate the proposed offset upstream dam construction method. The evaluation involved an assessment of the existing, near-term, and ultimate conditions. The objective of the assessment was to identify critical design issues with the 2003 proposed changes to the dam construction and to provide a basis for the design. The 2007 dam cross section configuration was used to calibrate observed piezometer, inclinometer, and seepage measurements for Dams 1 and 2. The 2004 dam cross section configuration was used for Dam 5. The dams were also evaluated for the proposed configuration at elevations 1,230 and 1,245 feet and for the ultimate configuration at elevation 1,315 feet. The dams were evaluated at elevation 1,315 feet to identify critical seepage or stability issues to allow the planning and completion of corrective measures during early-stage construction.

The results of the slope stability analyses for Dam 1 indicate that the computed factors of safety are adequate for both existing and near-term conditions. The analysis for the ultimate dam elevation indicates that, for all scenarios evaluated, the factors of safety meet the minimum recommended values except one. This scenario is for a block failure using the lower-bound direct simple shear strength and fine tailings yield strength. The computed factor of safety was 1.27, essentially 1.3, but less than the minimum recommended value of 1.3. This is not a great concern, because the crest elevation will not be reached for approximately 60 years. Careful management, ongoing evaluation, and monitoring will allow changes to the dam configuration prior to reaching the ultimate dam elevation. Additionally strength gain measurements and the use of the observational method for design and construction will allow for changes to be made based on observed behavior.

The results of the stability analysis of Dam 2 indicate that the computed factors of safety are adequate for both the existing and the remainder of the scenarios analyzed to the crest elevation of 1,315 feet. The ultimate elevation of 1,315 feet is stable and is likely due to the toe berm construction project in 1997 that was required for stability.

Stability results for Dam 5 predict factors of safety that meet the minimum recommended values. Future construction will include excavating the organic soils overlying the foundation clay within the seepage collection pond to construct a filter layer and toe drain over the foundations clays. The construction of this zone will allow for access to instrumentation and performance of additional future geotechnical studies in the area to validate assumptions used in this evaluation.

Through all studies at each dam section it became apparent that the safety factors for uplift at the toe of the dams may be less than generally accepted values based on conservative seepage models. At all dams the estimated total head for the piezometers located along the toe were greater than those measured, leading to conservative models. The elevated total heads result in lower estimated factors of safety against uplift. The actual piezometer readings were then used to calculate the resistance to uplift. The factors of safety are generally acceptable using the actual piezometer reported total head values along the toe of the dam for the existing conditions but in the case of Dam 1 are less than 1.5. The piezometers should be monitored over time as the dams are raised to monitor and predict the resistance to uplift along the toe of the dams.

In summary conservative analyses were completed on each of the dams at the tailings basin. The conservatism was addressed by using a range between the lower bound and average soil strengths and stability models including calculated total heads within the dam cross section that are greater than the measured piezometer values. The level of conservatism is appropriate for analyses performed for future phases of dam construction where conditions or construction methodology may change in the future. The analyses represent dam construction over 60 years of future operation of the facility. Based on the analyses, the models predict the dams are stable using the current construction practices and configurations. However a review of the resistance to uplift along the toe of Dam 1 is warranted. The following section discusses the recommendations for future work to validate some assumptions made during the analyses and to provide documentation of the conditions at each dam site.

8.2 Recommendations

The following list presents the recommendations that can be completed over the duration of the current five year operating plan and used to update and validate the stability of the dams. The recommendations are based on the conclusions of this evaluation.

- Continue the monitoring program at each of the dams to provide ongoing information. Create updated seepage and stability models based on this information.

- Monitor more closely the seepage and uplift at the toe of all the dams. This may require installation of additional piezometers to properly evaluate the pressures within the clay foundation. Compare the pressures to those calculated in the stability models as the pond level rises.

- Investigate the effects of the relief wells. Determine whether the relief wells are working and reducing the uplift pressures along the toe of the dam as intended in the original design. Modify the relief wells as necessary.

- Continue to measure the shear strength of the fine tailings using in-situ testing techniques and with bulk samples in the laboratory. This includes characterization of dilative or contractive behavior of the fine tailings relevant to liquefaction assessment in an ongoing process. This will allow the evaluation of the tailings liquefied strength to continue over time.

- Increase the knowledge base of the lacustrine clay foundation at Dam 5. The study shows the clay located within the foundation of Dam 5 may be different from clay observed at other portions of the site and affect the outcome of the seepage and stability analyses.

- Continue to evaluate the strength of the overconsolidated clay along the toe of Dams 1 and 2 because this material affects the factors of safety in the stability analyses since most of the failure surfaces in the model extend through this zone.

- Continue with construction of the filter blanket and toe drain along the entire planned area of Dam 5. This will increase stability of toe failures along the dam for the long-term design. Continue monitoring the seepage and uplift at this dam with new instrumentation along the toe and downstream of the glacial till cutoff.

- Continue to pursue the evaluation and construction of the plant aggregate stockpile along the toe of Dam 1.

9.0 References

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10.0 Glossary

CPT	cone penetration test
DSS	direct simple shear
ESSA	effective shear strength analysis test
GPM	gallons per minute
NSM	Northshore Mining Company
PSHA	probabilistic hazard analysis
SPT	standard penetration
TXC	triaxial compression
USSA	undrained shear strength analysis

Table 4.2.4 Permeability Values Proposed by Barr (2009)

Material	Permeability [cm/s] Vertical	Permeability [cm/s] Horizontal	Permeability Anisotropy (k_H/k_V)
Foundation Till	1.35×10^{-5}	1.22×10^{-4}	9
Lacustrine Clay (NC)	$1.10\text{x}10^{-9} – 4.80\text{x}10^{-6}$	$2.30\text{x}10^{-9} – 4.30\text{x}10^{-7}$	0.9± (Varies)
Lacustrine Clay (OC)	$5.60\text{x}10^{-9} – 6.70\text{x}10^{-8}$	$1.60\text{x}10^{-8} – 4.3\text{x}10^{-7}$	65± (Varies)
Sand and Gravel	$2.50\times10^{-4} – 5.0\text{x}10^{-2}$	$2.50\times10^{-4} – 5.0\text{x}10^{-2}$	1
Glacial Till Cutoff	$1.00\times10^{-7} – 6.60\text{x}10^{-7}$	$1.00\times10^{-7} – 6.60\text{x}10^{-7}$	1
Filter Material	2.00×10^{-3}	2.00×10^{-3}	1
Plant Aggregate	8.00×10^{-2}	8.00×10^{-2}	1
Fine Tailings/Slimes	4.0×10^{-5}	4.0×10^{-5}	1

Table 4.3.2.3 Summary of Recommended Strength Parameters

Material	Moist Unit Weight (pcf) (5)	Drained (ESSA) (Φ degrees)	Undrained (USSA) Strength Ratio (USSR) S_u/σ'_v	Undrained (USSA) Mohr-Coulomb C (psf)	Undrained (USSA) Mohr-Coulomb Φ (degrees)
Coarse Tailings	144	40	--	0	40
Filter Tailings	130	38	--	0	38
Glacial Till Cutoff	145	31	--	0	31
Foundation Till	145	28	0.28	--	--
Sand and Gravel Starter Dam	130	38	--	0	38
Lacustrine Clay near toe (OC)	113	Non-linear	--	680(5)	0
Fine Tailings – Yield Strength	130	24	0.2	--	--
Fine Tailings – Liquefied Strength	130	-	0.1	--	--
Block or Wedge Failure					
Lacustrine Clay	113	Non-linear (4)	--	0	Non-linear (2)
Circular or Compression Failure					
Lacustrine Clay	113	Non-linear (3)	--	0	Non-linear (1)

(ESSA): Effective Shear Strength Analysis
(USSR): Undrained Shear Strength Ratio
(USSA): Undrained Shear Strength Analysis
(OC): Overconsolidated
(1) Figure 4.3.2.3a
(2) Figure 4.3.2.3b
(3) Figure 4.3.2.3c
(4) Figure 4.3.2.3d
(5) Based on previously published data

Table 4.3.2.4.1a Historical Seismicity of Minnesota

Epicenter (nearest town)	Mo/day/yr	Lat.	Long.	Felt area (km^2)	Maximum intensity	Magnitude
1 Long Prairie	1860-61	46.1	94.9		VI-VII	5.0
2 New Prague	12/16/1860	44.6	93.5	—	VI	4.7
3 St. Vincent	12/28/1880	49.0	97.2	—	II-IV	3.6
4 New Ulm	2/5-2/12/1881	44.3	94.5	v.local	VI	3.0-4.0?
5 Red Lake	2/6/1917	47.9	95.0	—	V	3.8
6 Staples	9/3/1917	46.34	94.63	48,000	VI-VII	4.3
7 Bowstring	12/23/1928	47.5	93.8	—	IV	3.8
8 Detroit Lakes	1/28/1939	46.9	96.0	8,000	IV	3.9-3
9 Alexandria	2/15/1950	46.1	95.2	3,000	V	3.6
10 Pipestone*	9/28/1964	44.0	96.4	—	—	3.4
11 Morris*	7/9/1975	45.50	96.10	82,000	VI	4.8-4.6
12 Milaca*	3/5/1979	45.85	93.75	—	—	1.0
13 Evergreen*	4/16/1979	46.78	95.55	—	—	3.1
14 Rush City*	5/14/1979	45.72	92.9	—	—	0.1
15 Nisswa*	7/26/1979	46.50	94.33	v.local	III	1.0
16 Cottage Grove	4/24/1981	44.84	92.93	v.local	III-IV	3.6
17 Walker	9/27/1982	47.10	97.6	v.local	II	2.0
18 Dumont*	6/4/1993	45.67	96.29	69,500	V-VI	4.1
19 Granite Falls*	2/9/1994	44.86	95.56	11,600	V	3.1

[Asterisks denote earthquakes that were recorded instrumentally. All others and associated magnitudes based solely on intensity data from felt reports.]

Table 4.3.2.4.1b Results of USGS Web Report

Results of USGS Web Report		
Conterminous 48 States		
2002 Data		
Uniform Hazard Spectrum (UHS) for 2 % PE in 50 years		
Zip Code - 55601		
Zip Code Latitude = 47.258202		
Zip Code Longitude = -91.3013		
B/C Boundary		
Data are based on a 0.05 deg grid spacing		
Period (sec)	**Sa (g)**	**Sd (inches)**
0.000	0.024	0.000
0.100	0.059	0.006
0.200	0.056	0.022
0.300	0.044	0.039
0.500	0.030	0.073
1.000	0.017	0.162
2.000	0.008	0.320

Table 4.3.2.41c Summary of Seismic Risk Calculation

Probability of Exceedance Per Annum	**Probability of Exceedance**		
	.0021	**0.001**	**0.0004**
In 50 years	10%	5%	2%
Return Period [years]	475	975	2,475
Peak Ground Acceleration [g]	0.006	0.012	0.024

Table 4.4.2 Procedure for Dam Stability Analyses

Fine Tailings Yield Strength Analysis			
Circular Failure			
Direct Simple Shear Lower Bound	Direct Simple Shear Average	Triaxial Lower Bound	Triaxial Average
Block Failure			
Direct Simple Shear Lower Bound	Direct Simple Shear Average	Triaxial Lower Bound	Triaxial Average
Fine Tailings Liquefied Strength Analysis			
Circular Failure			
Direct Simple Shear Lower Bound	Direct Simple Shear Average	Triaxial Lower Bound	Triaxial Average
Block Failure			
Direct Simple Shear Lower Bound	Direct Simple Shear Average	Triaxial Lower Bound	Triaxial Average

Table 5.1.1.2a Comparison of Measured and Predicted Total Heads for Dam 1 (Existing)

Piezometer	Measured Head [ft]	SEEP/W Head [ft]	Difference [ft]	Material
3B-P1	1145.8	1144.6	1.2	Foundation Till
3B-P2	1134.1	1146.0	-11.9	Lacustrine Clay
3B-P3	1133.7	1144.4	-10.7	Lacustrine Clay
3F-P1	1133.5	1140.8	-7.3	Lacustrine Clay
3F-P2	1139.2	1138.0	1.2	Lacustrine Clay
2G-P1	1140.5	1147.2	-6.7	Lacustrine Clay
2G-P2	1137.5	1145.1	-7.6	Lacustrine Clay
3I-P2	1194.2	1192.9	1.3	Fine Tailings
3K-P1	1197.1	1194.6	2.5	Fine Tailings
3K-P2	1183.7	1194.8	-11.1	Fine Tailings
P97-1	1136.4	1142.4	-6.0	Foundation Till
P97-10A	1196.3	1197.0	-0.7	Fine Tailings
P97-10B	1196.8	1196.9	-0.1	Fine Tailings
P97-10C	1197.5	1196.8	0.7	Fine Tailings

(Negative value indicates excess total head).

Table 5.1.1.2b Revised Permeabilities Used in Seepage Analysis, Dam 1

Material	Permeability [cm/s]		Permeability Anisotropy (k_H/k_V)
	Vertical	Horizontal	
Foundation Till	1.35×10^{-5}	1.22×10^{-4}	9
Lacustrine Clay (NC)	7.9×10^{-7}	7.46×10^{-7}	0.94
Lacustrine Clay (OC)	2.3×10^{-7}	1.5×10^{-5}	65
Sand and Gravel	1.0×10^{-1}	1.0×10^{-1}	1
Glacial Till Cutoff	1.0×10^{-7}	1.0×10^{-7}	1
Filter Material	2.0×10^{-3}	2.0×10^{-3}	1
Plant Aggregate	8.0×10^{-2}	8.0×10^{-2}	1
Fine Tailings/Slimes	4.0×10^{-5}	4.0×10^{-5}	1

Table 5.2 Computed Uplift at Toe of Dam 1 Based on Model Parameters

Dam Elevation (ft)	Calculated Factor of Safety Against Uplift (from model)	Estimated Factor of Safety Against Uplift
1215	1.04	1.31 (actual from instrumentation)
1230	1.03	1.30
1245	1.01	1.27
1315	0.97	1.22

Table 5.3.1.1 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 1, Existing Geometry (Crest Elevation = 1215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
	Fine Tailings USSR=0.2 (yield)			
Circular	1.44	1.44	1.44	1.44
Block	1.50	1.89	1.85	2.10

DSS: Direct Simple Shear
TXC: Triaxial Compression
USSR: Undrained Shear Strength Ratio

Table 5.3.1.2 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 1, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Fine Tailings USSR=0.2 (yield)			
Circular	1.43	1.43	1.43	1.43
Block	1.50	1.88	1.84	2.09
Crest Elevation = 1245				
	Fine Tailings USSR=0.2 (yield)			
Circular	1.41	1.41	1.41	1.41
Block	1.53	1.88	1.85	2.09
Crest Elevation = 1315				
	Fine Tailings USSR=0.2 (yield)			
Circular	1.43	1.46	1.46	1.47
Block	1.27	1.65	1.62	1.89

DSS: Direct Simple Shear
TXC: Triaxial Compression
USSR: Undrained Shear Strength Ratio

Table 5.3.2.1 Results of the Slope Stability Analysis (ESSA), Factors of Safety, Dam 1, Existing Geometry (Crest Elevation = 1215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Circular	2.00	2.11	2.04	2.13
Block	1.59	2.21	1.87	2.46

DSS: Direct Simple Shear
TXC: Triaxial Compression

Table 5.3.2.2 Results of the Slope Stability Analysis (ESSA), Factors of Safety, Dam 1, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
Circular	1.97	2.08	2.00	2.09
Block	1.57	2.19	1.83	2.41
Crest Elevation = 1245				
Circular	1.94	2.05	1.98	2.07
Block	1.55	2.17	1.82	2.39
Crest Elevation = 1315				
Circular	2.09	2.16	2.14	2.22
Block	1.51	2.14	1.77	2.34

DSS: Direct Simple Shear
TXC: Triaxial Compression

Table 5.3.3.1 Results of the Slope Stability Analysis (Liquefied Strength), Factors of Safety, Dam 1, Existing Geometry (Crest Elevation = 1215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
	Fine Tailings $USSR_{liq}$=0.1 (liquefied)			
Circular	1.44	1.44	1.44	1.44
Block	2.41	1.89	1.85	2.10

DSS: Direct Simple Shear
TXC: Triaxial Compression
$USSR_{liq}$: Liquefied Strength

Table 5.3.3.2 Results of the Slope Stability Analysis (Liquefied Strength), Factors of Safety, Dam 1, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Fine Tailings $USSR_{liq}$ =0.1 (liquefied)			
Circular	1.44	1.44	1.44	1.44
Block	1.50	1.88	1.84	2.09
Crest Elevation = 1245				
	Fine Tailings $USSR_{liq}$ =0.1 (liquefied)			
Circular	1.41	1.41	1.41	1.41
Block	1.53	1.88	1.85	2.09
Crest Elevation = 1315				
	Fine Tailings $USSR_{liq}$ =0.1 (liquefied)			
Circular	1.39	1.41	1.41	1.42
Block	1.19	1.58	1.55	1.83

DSS: Direct Simple Shear
TXC: Triaxial Compression
$USSR_{liq}$: Liquefied Strength

Table 6.1.1.1 Revised Permeabilities Used in Seepage Analysis, Dam 2

Material	Permeability [cm/s]	Permeability Anisotropy (k_H/k_V)
Foundation Till	3.96×10^{-5}	1
Lacustrine Clay (NC)	1.86×10^{-7}	1
Lacustrine Clay (OC)	1.40×10^{-6}	1
Sand and Gravel	1.00×10^{-1}	1
Glacial Till Cutoff	1.00×10^{-7}	1
Filter Material	2.00×10^{-3}	1
Plant Aggregate	8.00×10^{-2}	1
Fine Tailings/Slimes	4.0×10^{-5}	1

Table 6.1.1.2 Comparison of Measured and Predicted Total Heads for Dam 2 (Existing)

Piezometer	Measured Head [ft]	SEEP/W Head [ft]	Difference [ft]	Material
18B (Sec. 42+00)	1194.5	1196.0	-1.5	Plant Aggregate
18C (Sec. 42+00)	1193.2	1196.0	-2.8	Plant Aggregate
19B	1183.4	1195.9	-12.5	Fine Tailings/Slimes
D2-3475-R100B	1193.5	1195.3	-1.8	Fine Tailings/Slimes
D2-3475-R100B	1192.0	1195.2	-3.2	Fine Tailings/Slimes
D2-3475-R100B	1192.0	1195.2	-3.2	Fine Tailings/Slimes
D2-3475-R100B	1191.3	1194.1	-2.8	Lacustrine Clay
D2-3475-R100B	1193.5	1192.6	0.9	Lacustrine Clay
D2-3475-R100B	1187.9	1191.3	-3.4	Foundation Till
3H-P1	1196.6	1184.2	12.4	Lacustrine Clay
3H-P2	1199.8	1188.0	11.8	Lacustrine Clay
3B-P5	1161.1	1159	2.1	Filter Material
3B-P4	1162.6	1162.5	0.1	Lacustrine Clay
3B-P3	1163.5	1165.0	-1.5	Lacustrine Clay
3B-P2	1166.5	1168.9	-2.4	Foundation Till
3B-P1	1171.5	1169.0	2.5	Foundation Till
3E-P1	1159.1	1161.2	-2.1	Lacustrine Clay
3E-P2	1158.3	1159.9	-1.6	Lacustrine Clay

(Negative value indicates excess total head).

Table 6.2 Computed Uplift at Toe of Dam 2

Dam Elevation (ft)	Calculated Factor of Safety Against Uplift (from model)
1215	1.48
1230	1.47
1245	1.46
1315	1.43

Table 6.3.1.1 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 2, Existing Geometry (Crest Elevation = 1,215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
	Fine Tailings USSR=0.2			
Circular	1.71	1.79	1.79	1.84
Block	1.71	2.06	2.03	2.29

DSS: Direct Simple Shear
TXC: Triaxial Compression
USSR: Undrained Shear Strength Ratio

Table 6.3.1.2 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 2, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Fine Tailings USSR=0.2			
Circular	1.75	1.82	1.82	1.87
Block	1.73	2.09	2.06	2.31
Crest Elevation = 1245				
	Fine Tailings USSR=0.2			
Circular	1.71	1.78	1.78	1.83
Block	1.70	2.05	2.02	2.28
Crest Elevation = 1315				
	Fine Tailings USSR=0.2			
Circular	1.63	1.75	1.74	1.76
Block	1.46	1.89	1.83	2.12

DSS: Direct Simple Shear
TXC: Triaxial Compression
USSR: Undrained Shear Strength Ratio

Table 6.3.2.1 Results of the Slope Stability Analysis (ESSA), Factors of Safety, Dam 2, Existing Geometry (Crest Elevation = 1,215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Circular	2.53	2.90	2.83	2.97
Block	2.03	2.89	2.50	3.33

DSS: Direct Simple Shear
TXC: Triaxial Compression

Table 6.3.2.2 Results of the Slope Stability Analysis (ESSA), Factors of Safety, Dam 2, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
Circular	2.55	2.89	2.81	2.95
Block	2.01	2.88	2.48	3.31
Crest Elevation = 1245				
Circular	2.52	2.89	2.81	2.95
Block	2.01	2.88	2.48	3.31
Crest Elevation = 1315				
Circular	2.73	2.86	2.81	2.93
Block	2.04	2.81	2.52	3.34

DSS: Direct Simple Shear
TXC: Triaxial Compression

Table 6.3.3.1 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 2, Existing Geometry (Crest Elevation = 1,215)

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
	Fine Tailings $USSR_{liq}$=0.1			
Circular	1.71	1.79	1.79	1.84
Block	1.70	2.06	2.03	2.29

DSS: Direct Simple Shear
TXC: Triaxial Compression
$USSR_{liq}$: Liquefied Strength

Table 6.3.3.2 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 2, Proposed Geometry

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Fine Tailings $USSR_{liq}$=0.1			
Circular	1.72	1.80	1.79	1.85
Block	1.74	2.08	2.05	2.32
Crest Elevation = 1245				
	Fine Tailings $USSR_{liq}$=0.1			
Circular	1.70	1.78	1.78	1.83
Block	1.70	2.05	2.02	2.32
Crest Elevation = 1315				
	Fine Tailings $USSR_{liq}$=0.1			
Circular	1.62	1.65	1.64	1.66
Block	1.31	1.74	1.68	1.96

DSS: Direct Simple Shear
TXC: Triaxial Compression
$USSR_{liq}$: Liquefied Strength

Table 7.1.1 Permeabilities Used in Seepage Analysis, Dam 5

Material	Permeability [cm/s]		Permeability Anisotropy (k_H/k_V)
	Vertical	Horizontal	
Bedrock	1.00×10^{-3}	1.00×10^{-3}	1.00
Foundation Till	1.35×10^{-5}	1.22×10^{-4}	9.00
Lacustrine Clay (NC)	7.90×10^{-7}	7.46×10^{-7}	0.94
Glacial Till Cutoff	1.00×10^{-4}	1.00×10^{-4}	1.00
Filter Material	2.00×10^{-3}	2.00×10^{-3}	1.00
Plant Aggregate	8.00×10^{-2}	8.00×10^{-2}	1.00

Table 7.1.2 Comparison of Measured and Predicted Total Heads for Dam 5 (Existing)

Piezometer	Measured Head [ft]	SEEP/W Head [ft]	Difference [ft]	Material
D5-VW-1390R30 Top	1176.3	1173.8	2.50	Filter Material
D5-VW-1390R30 Bottom	1185.6	1181.2	4.40	Foundation Till
D5-VW-1400R235 Top	1170.8	1174.3	-3.50	Lacustrine Clay
D5-VW-1400R235 Bottom	1176.3	1178.4	-2.10	Lacustrine Clay
D5-VW-1390R235	1182.6	1180.3	2.30	Foundation Till

(Negative value indicates excess total head).

Table 7.2 Computed Uplift at Toe of Dam 5 Proposed Dam Configuration

Dam Elevation (ft)	Calculated Factor of Safety Against Uplift (from model)
1215	1.20
1230	1.24
1245	1.23
1315	-

Table 7.3.2.1 Results of the Slope Stability Analysis (USSA), Factors of Safety, Dam 5, Proposed Geometry with Toe Drainage Blanket

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Low Pond (Toe)			
Circular	1.60	1.80	1.80	1.85
Block	1.43	2.11	2.06	2.48
	High Pond (Toe)			
Circular	1.72	1.82	1.82	1.85
Block	1.47	2.13	2.09	2.51
Crest Elevation = 1245				
	Low Pond (Toe)			
Circular	1.68	1.84	1.84	1.91
Block	1.56	2.14	2.09	2.52
	High Pond (Toe)			
Circular	1.74	1.87	1.87	1.88
Block	1.54	2.12	2.03	2.49
Crest Elevation = 1315				
	No Pond (Toe)			
Circular	2.04	2.04	2.04	2.04
Block	2.06	2.43	2.40	2.67

DSS: Direct Simple Shear
TXC: Triaxial Compression

Table 7.3.2.2 Results of the Slope Stability Analysis (ESSA), Factors of Safety, Dam 5, Proposed Geometry with Toe Drainage Blanket

Failure Mode	DSS		TXC	
	Low	Average	Low	Average
Crest Elevation = 1230				
	Low Pond (Toe)			
Circular	2.24	2.65	2.44	2.75
Block	1.99	2.74	2.32	3.06
	High Pond (Toe)			
Circular	2.51	2.75	2.64	2.81
Block	2.02	2.73	2.44	3.08
Crest Elevation = 1245				
	Low Pond (Toe)			
Circular	2.37	2.68	2.53	2.78
Block	2.08	2.77	2.41	3.10
	High Pond (Toe)			
Circular	2.50	2.50	2.63	2.82
Block	2.05	2.74	2.41	3.08
Crest Elevation = 1315				
	No Pond (Toe)			
Circular	3.22	3.28	3.30	3.33
Block	2.45	3.07	3.26	3.57

DSS: Direct Simple Shear
TXC: Triaxial Compression

Appendix A

Site Drawings

Xrefs in Drawing – M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
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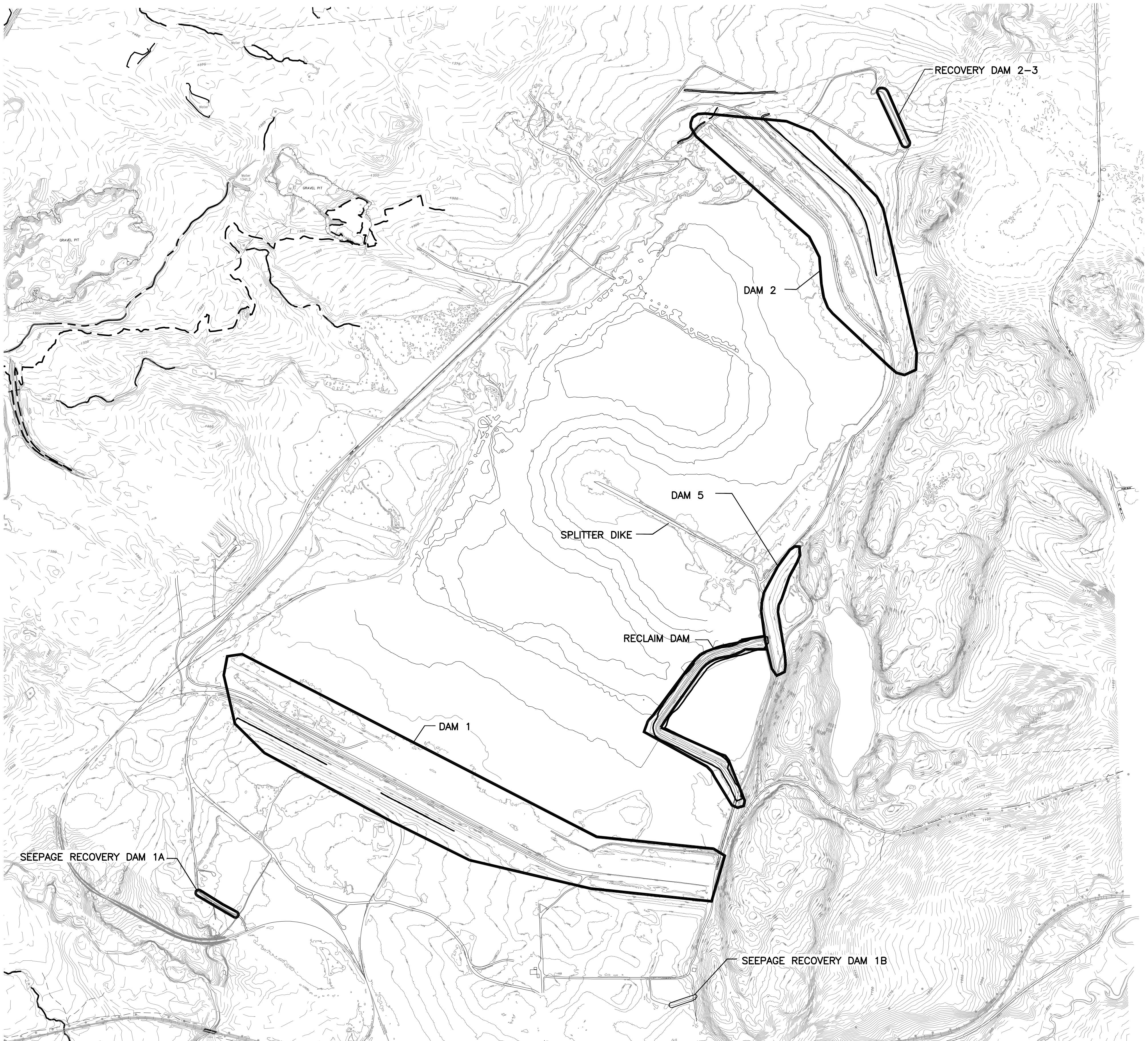

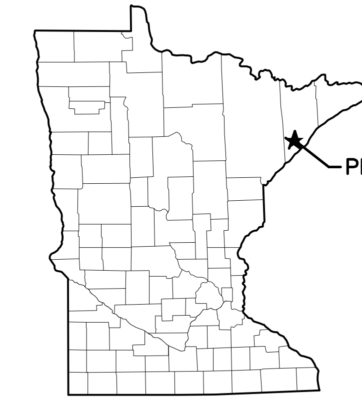

LOCATION MAP

INDEX

SHEET NO.	TITLE
G-01	BASIN SITE PLAN
G-02	DAM 1 PLAN VIEW
G-03	DAM 1 PLAN VIEW WITH BORING, CPT, AND BEACH SAMPLE LOCATIONS
G-04	DAM 1 – STA. 28+40 CROSS SECTION OF EXISTING CONDITIONS
G-05	DAM 1 – STA. 35+00 CROSS SECTION OF EXISTING CONDITIONS
G-06	DAM 2 PLAN VIEW
G-07	DAM 2 PLAN VIEW WITH BORING AND CPT LOCATIONS
G-08	DAM 2 – STA. 34+75 CROSS SECTION OF EXISTING CONDITIONS
G-09	DAM 2 – STA. 42+00 CROSS SECTION OF EXISTING CONDITIONS
G-10	SPLITTER DIKE PLAN WITH CPT LOCATIONS
G-11	DAM 5 – PLAN VIEW
G-12	DAM 5 – TYPICAL DESIGN SECTIONS 8+00 AND 14+00
G-13	DAM 5 – TYPICAL DESIGN SECTION 24+00

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BID							
CONSTRUCTION							
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Scale	AS SHOWN
Date	7/16/09
Drawn	GSJ
Checked	ATG
Designed	MLK2
Approved	ATG

NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION
BASIN SITE PLAN

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-01
REV. No. 0

gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-02.DWG Plot at 96 07/13/2009 15:07:33

1 PLAN: DAM 1

0 400 800
SCALE IN FEET

DAM 1 2005 BORING AND CPT SOUNDING LOCATIONS

BORING/CPT ID	COORDINATES		ELEVATION
STATION AND OFFSET	NORTHING	EASTING	(FEET)
D1-2840-R100A	618534.53	3051533.47	1211.58
D1-2840-R100B	61859.00	3051525.79	1211.85
D1-2840-R750	617925.99	3051199.83	1217.39
D1-2840-R1200	61753.58	3050997.56	1139.63
D1-3500-L100A	618364.58	3052163.50	1207.82
D1-3500-L100B	618350.48	3052186.52	1207.91
D1-3500-R100A	618146.54	3052066.19	1210.74
D1-3500-R100B	618162.41	3052076.00	1210.80
D1-3500-R1200	617211.73	3051577.56	1137.23
CPT-D1-2840-L100	618673.06	3051599.30	1206.97
CPT-D1-2840-R100	618544.77	3051537.73	1211.50
CPT-D1-2840-R200	618411.81	3051457.06	1211.43
CPT-D1-2840-R450	618186.71	3051344.02	1205.90
CPT-D1-3500-L300	618283.63	3052475.28	1204.93
CPT-D1-3500-L100	618357.19	3052174.86	1207.78
CPT-D1-3500-CL	618241.80	3052120.94	1210.62
CPT-D1-3500-R100	618172.20	3052083.16	1210.60
CPT-D1-3500-R200	618097.59	3051999.23	1211.22
CPT-D1-3500-R450	617865.97	3051926.2	1206.49
CPT-D1-3500-R1200	617216.92	3051580.24	1137.62

LAYOUT NOTES:

1. LAYOUT BASED ON CONTOURS DEVELOPED FROM AERIAL SURVEY BY AERO-METRIC OF SHEYBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY MAY 24, 2008. AERO-METRIC MAPPING BASED ON THE FOLLOWING DATUM:

- VERTICAL DATUM: TWO FOOT CONTOUR INTERVAL BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988.
- HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

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SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

DAM 1
PLAN VIEW

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-02
REV. No. A

Xrefs in Drawing – M:\cad\2338086\21298_1.DWG M:\cad\N_shore\2338_086\2007 DAM INSPECTION\20276_1.dwg M:\cad\2338086\20278_1.dwg M:\cad\2338086\20907_1.DWG M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
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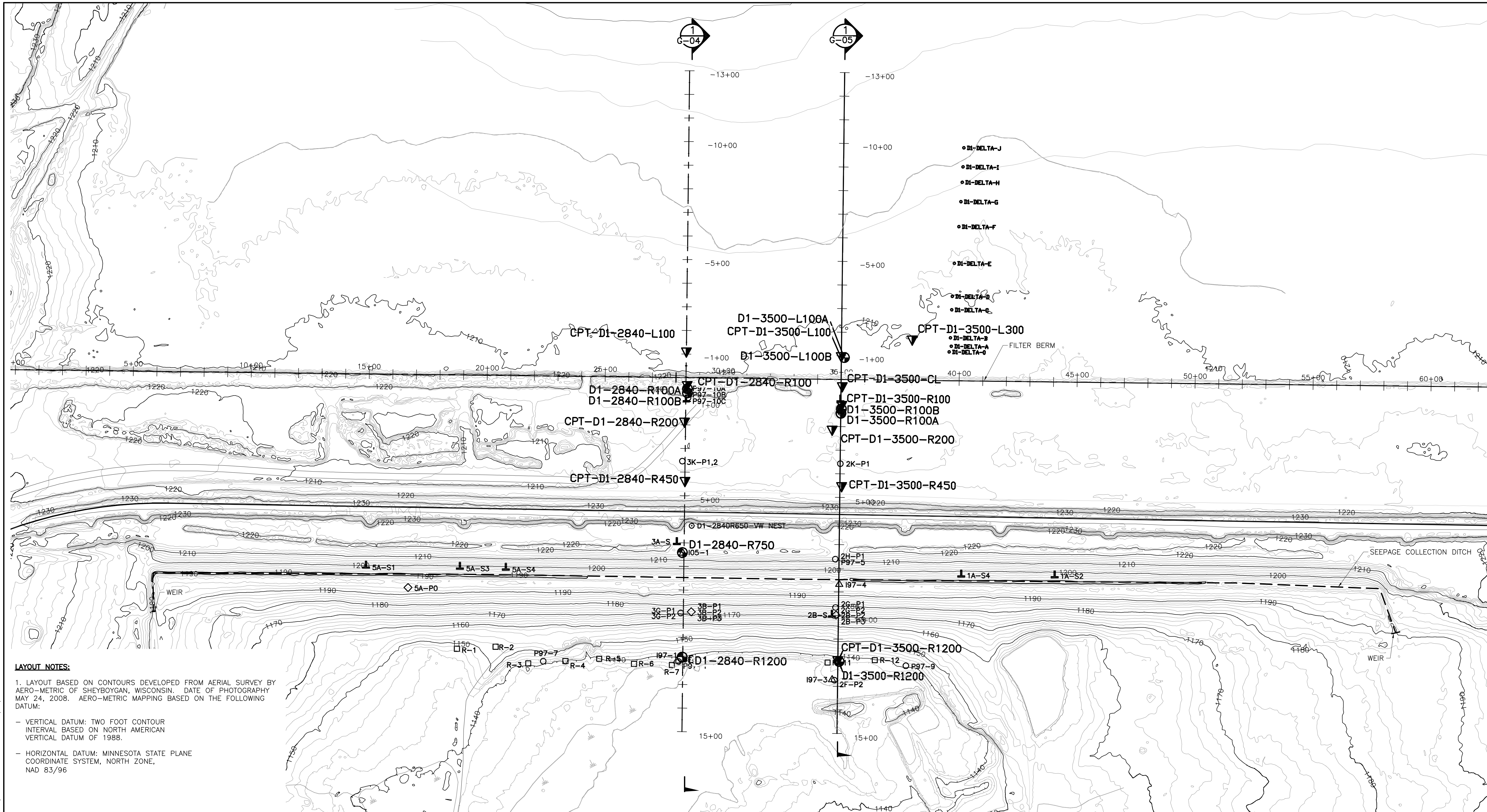

LAYOUT NOTES:

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– HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

2 PLAN: DAM 1

0 200 400
SCALE IN FEET

LEGEND:

BORING LOCATION

CPT SOUNDING LOCATION

BEACH SAMPLE LOCATION

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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CONSTRUCTION							
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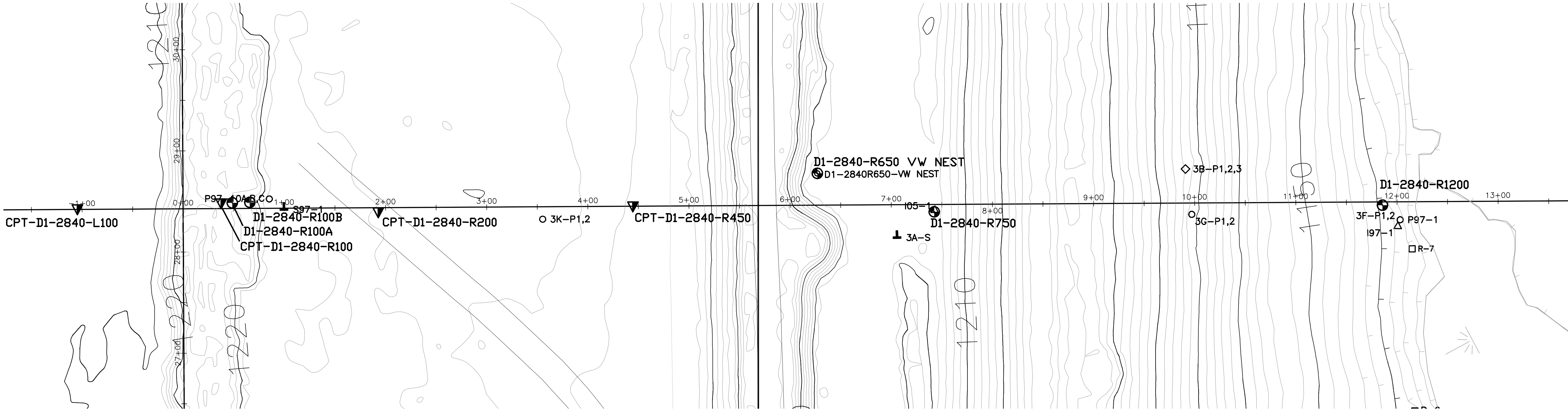
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

DAM 1 PLAN VIEW WITH BORING, CPT, AND BEACH SAMPLE LOCATIONS

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-03
REV. No. A

gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-04.dwg Plot at 1 07/13/2009 14:58:28



1 G-03 PLAN: DAM 1 – STA. 28+40

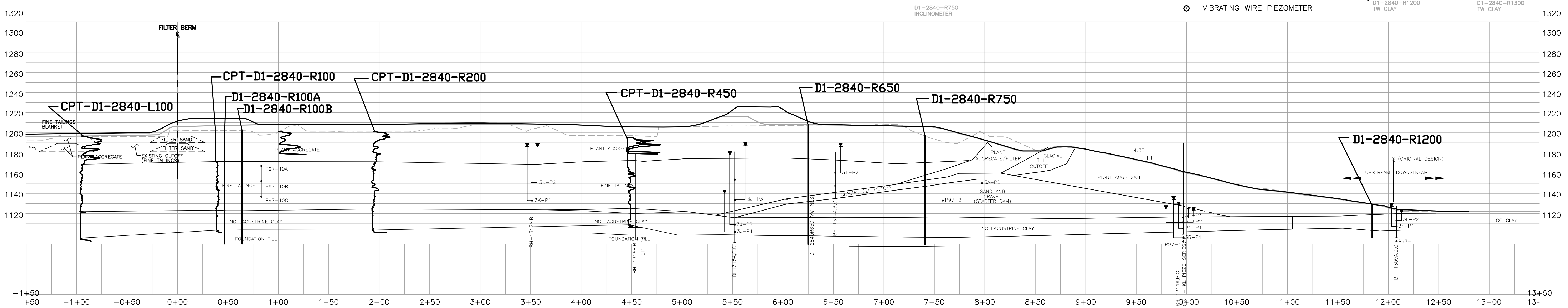
0 50 100 SCALE IN FEET

LEGEND:

- O PNEUMATIC PIEZOMETER
- ◇ CASAGRANDE PIEZOMETER
- △ INCLINOMETER
- □ RELIEF WELL
- ⊥ SETTLEMENT PLATE
- ⊙ VIBRATING WIRE PIEZOMETER

2005 INVESTIGATION:

- BORING LOCATION
- CPT LOCATION



1 G-03 SECTION: DAM 1 – STA. 28+40

0 50 100 SCALE IN FEET

NOTE: CROSS SECTION SURFACE DEVELOPED FROM 2007 FLYOVER.

2007 VIBRATING WIRE PIEZOMETER INSTALLATION:

D1-2840-R650	ELEVATION	S/N
FINE TAILINGS	1168	29426
DAM FILL	1132	29427
LACUSTRINE CLAY	1123	29428
GLACIAL TILL	1110	29429

LEGEND

– – –?– – – UNAVAILABLE INFORMATION FOR ACCURATE CONTACT INTERPRETATION

STRATIGRAPHIC CONTACTS BETWEEN FOUNDATION SOILS ARE BASED ON INTERPRETATION BETWEEN BORINGS. CONTACTS BETWEEN INTERNAL DAM FILL ZONES ARE BASED ON INTERPRETATION BETWEEN BORINGS AND CONSTRUCTION RECORDS INFORMATION, WHERE AVAILABLE.

CPT CONE BEARING PRESSURE VS. ELEVATION

INVESTIGATIVE BORING

PIEZOMETRIC LEVEL (10/11/05)

3F-P2 PIEZOMETER IDENTIFIER

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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CLIENT	7/15						
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CONSTRUCTION							
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Scale	AS SHOWN
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Designed	ATG
Approved	ATG

NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILINGS POND
GEOTECHNICAL EVALUATION

DAM 1 – STA. 28+40
CROSS SECTION OF EXISTING CONDITIONS

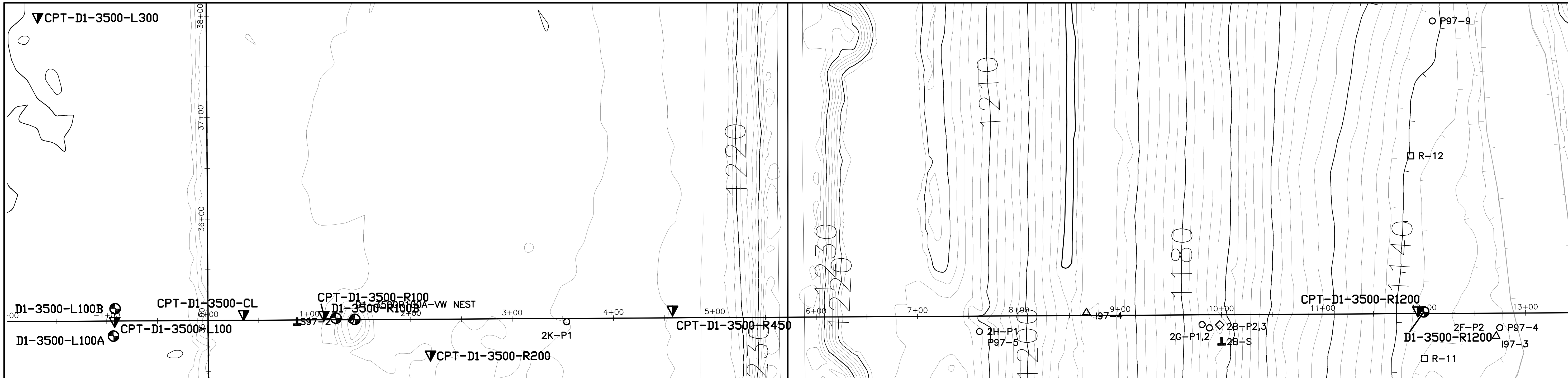
BARR PROJECT No. 23/38-086

CLIENT PROJECT No.

DWG. No. G-04

REV. No. A

gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-05.DWG Plot at 96 07/13/2009 14:55:48



PLAN: DAM 1 – STA. 35+00

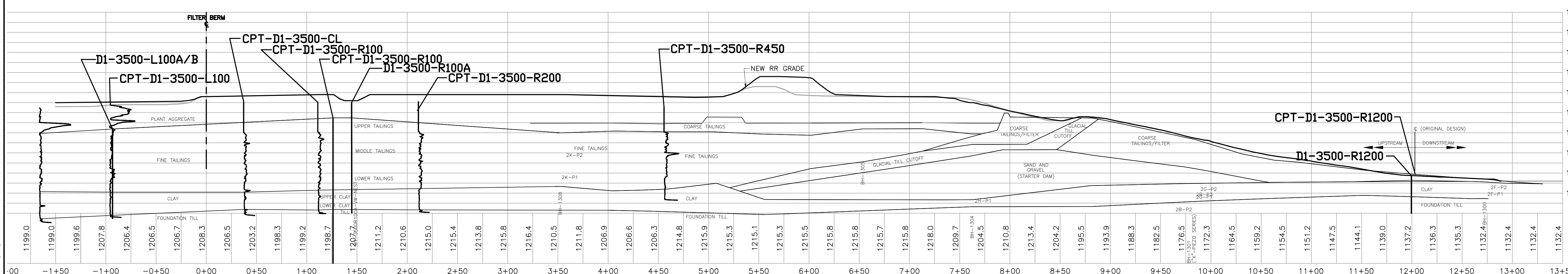
(1 / G-03)

0 50 100
SCALE IN FEET

LEGEND:

PREVIOUSLY INSTALLED INSTRUMENTS:
- ○ PNEUMATIC PIEZOMETER
- ◇ CASAGRANDE PIEZOMETER
- △ INCLINOMETER
- □ RELIEF WELL
- ⊥ SETTLEMENT PLATE
- ⊙ VIBRATING WIRE PIEZOMETER

2005 INVESTIGATION:
- BORING LOCATION
- ▼ CPT LOCATION



SECTION: DAM 1 – STA. 35+00

(1 / G-03)

0 50 100
SCALE IN FEET

NOTE: CROSS SECTION SURFACE DEVELOPED FROM 2007 FLYOVER.

2005 VIBRATING WIRE PIEZOMETER INSTALLATION:

D1-3500-R100A	ELEVATION	S/N
UPPER TAILINGS	1185.7	83353
MIDDLE TAILINGS	1160.7	83352
LOWER TAILINGS	1133.7	83358
UPPER CLAY	1115.7	83350
LOWER CLAY	1106.7	83355
TILL	1101.7	83348

LEGEND

– – –?– – – UNAVAILABLE INFORMATION FOR ACCURATE CONTACT INTERPRETATION

———— STRATIGRAPHIC CONTACTS BETWEEN FOUNDATION SOILS ARE BASED ON INTERPRETATION BETWEEN BORINGS. CONTACTS BETWEEN INTERNAL DAM FILL ZONES ARE BASED ON INTERPRETATION BETWEEN BORINGS AND CONSTRUCTION RECORDS INFORMATION, WHERE AVAILABLE.

CPT CONE BEARING PRESSURE VS. ELEVATION

INVESTIGATIVE BORING
PIEZOMETRIC LEVEL (10/11/05)
3F-P2 — PIEZOMETER IDENTIFIER

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION
DAM 1 – STA. 35+00
CROSS SECTION OF EXISTING CONDITIONS

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-05
REV. No. A

Xrefs in Drawing – M:\cad\2338086\21789_1.dwg M:\cad\2338086\20276_1.dwg M:\cad\N_shore\2338_086\Geotechnical\xref\20278_1.dwg M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-06.DWG Plot at 1 07/13/2009 14:53:33

DAM 2 2005 BORING AND CPT SOUNDING LOCATIONS

BORING/CPT ID STATION AND OFFSET	COORDINATES NORTHING	COORDINATES EASTING	ELEVATION (FEET)
D2-3475-R100B	628235.99	3059662.99	1206.94
D2-3475-L100A	628078.98	3059485.71	1205.06
D2-3475-L100B	628058.55	3059507.91	1205.33
D2-4200-L100A	628538.38	3058946.70	1206.83
D2-4200-L100B	628519.92	3058967.46	1207.22
CPT-D2-3475-L100	628046.02	3059498.53	1206.33
CPT-D2-3475-CL	628111.30	3059550.43	1213.15
CPT-D2-3475-R100	628196.35	3059625.92	1207.35
CPT-D2-3475-R300	628355.61	3059771.17	1198.29
CPT-D2-4200-L100	628519.93	3058965.69	1206.90
CPT-D2-4200-CL	628592.80	3059009.88	1214.20
CPT-D2-4200-R200	628715.71	3059124.04	1206.02
CPT-D2-4200-R300	628836.69	3059234.95	1198.62
CPT-D2-4200-R1200	629275.80	3059710.83	1170.95

LAYOUT NOTES:

1. LAYOUT BASED ON CONTOURS DEVELOPED FROM AERIAL SURVEY BY AERO-METRIC OF SHEYBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY MAY 24, 2008. AERO-METRIC MAPPING BASED ON THE FOLLOWING DATUM:

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– HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

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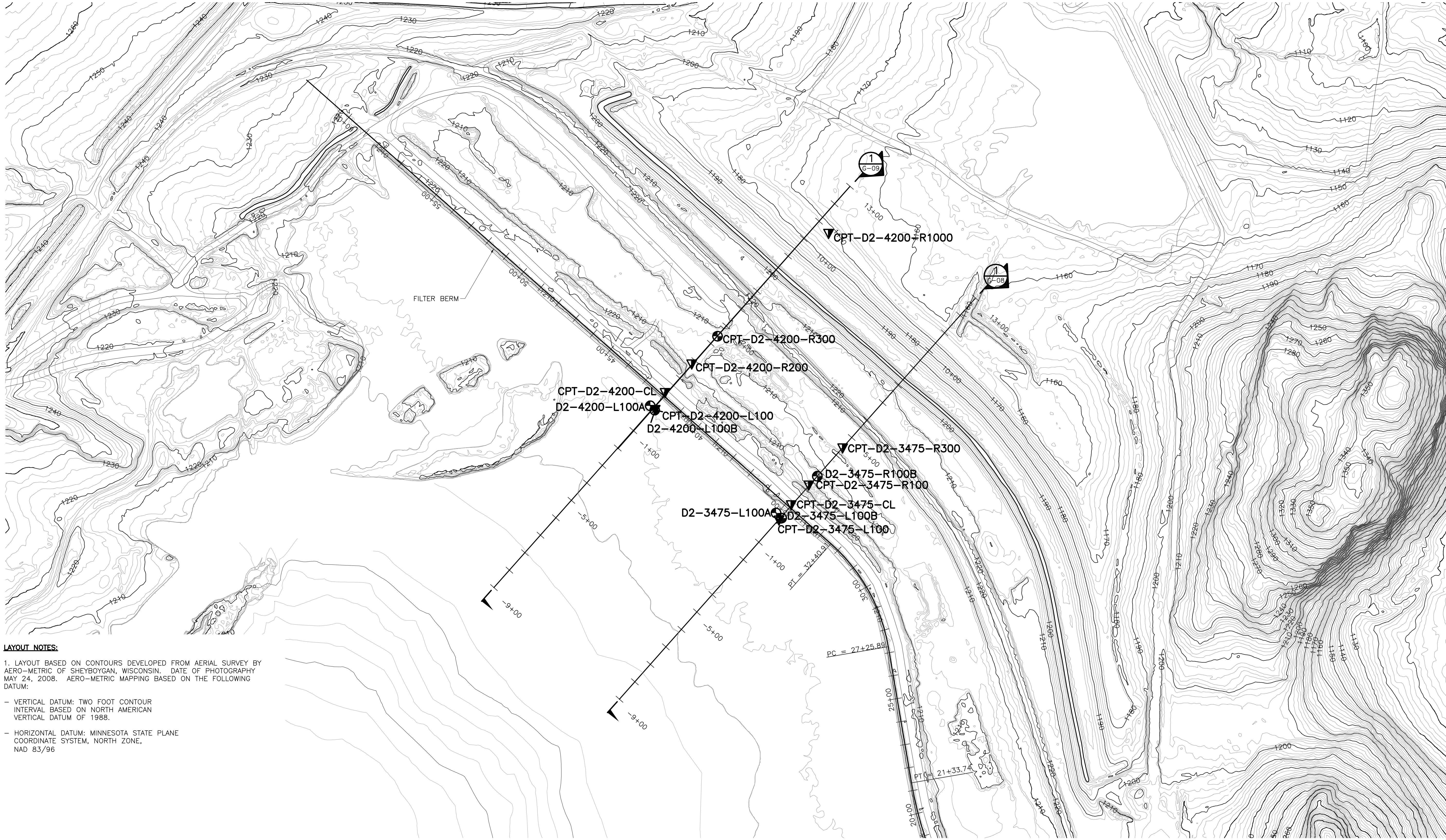
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

DAM 2
PLAN VIEW

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-06
REV. No. A

Xrefs in Drawing – M:\cad\2338086\20431_1.DWG M:\cad\2338086\21789_1.dwg M:\cad\N_shore\2338_086\2007 DAM INSPECTION\20276_1.dwg M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-07.DWG Plot at 1 07/13/2009 14:46:21



LAYOUT NOTES:

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– HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

LEGEND:

BORING LOCATION

CPT SOUNDING LOCATION

1 PLAN: DAM 2 – STA. 0+00 TO 60+00

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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PRINTED NAME ______

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CONSTRUCTION							

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Designed	ATG
Approved	ATG

NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

INSTRUMENTATION DRAWING
DAM 2 – PLAN VIEW

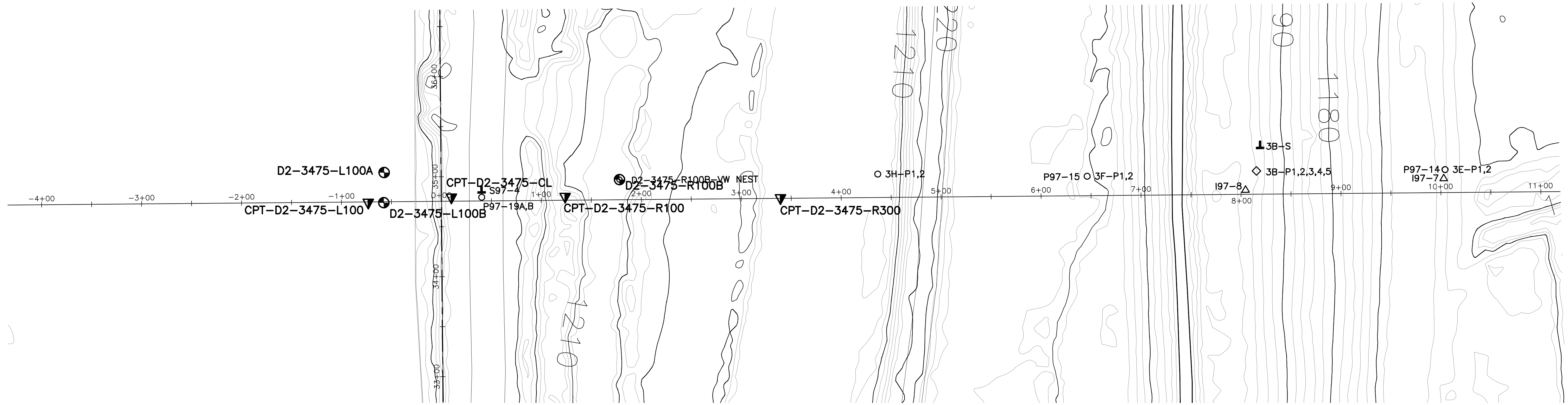
BARR PROJECT No. 23/38-086

CLIENT PROJECT No.

DWG. No. G-07

REV. No. A

gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-08.DWG Plot at 0 07/13/2009 14:43:58



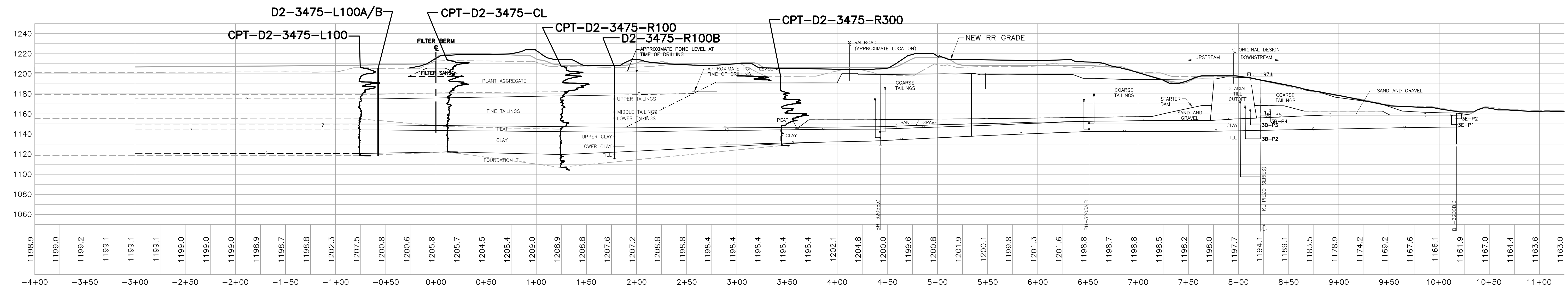
PLAN: DAM 2 - STA. 34+75

0 50 100
SCALE IN FEET

LEGEND:

PREVIOUSLY INSTALLED INSTRUMENTS:
- PNEUMATIC PIEZOMETER
- CASAGRANDE PIEZOMETER
- INCLINOMETER
- RELIEF WELL
- SETTLEMENT PLATE

2005 INVESTIGATION:
- BORING LOCATION
- CPT LOCATION



-4+00	-3+50	-3+00	-2+50	-2+00	-1+50	-1+00	-0+50	0+00	0+50	1+00	1+50	2+00	2+50	3+00	3+50	4+00	4+50	5+00	5+50	6+00	6+50	7+00	7+50	8+00	8+50	9+00	9+50	10+00	10+50	11+00
1198.9	1199.2	1199.1	1199.0	1199.0	1198.7	1202.3	1200.8	1205.8	1204.5	1209.0	1208.8	1207.2	1198.8	1198.4	1198.4	1202.1	1200.0	1200.8	1200.1	1201.3	1198.8	1198.8	1198.2	1197.7	1189.1	1178.9	1169.2	1166.1	1167.0	1163.6
1199.0	1199.1	1199.1	1199.0	1198.9	1198.8	1207.5	1200.6	1205.7	1208.4	1208.9	1207.6	1208.8	1198.4	1198.4	1198.4	1204.8	1199.6	1201.9	1199.8	1201.6	1198.7	1198.5	1198.0	1194.1	1183.5	1174.2	1167.6	1161.9	1164.4	1163.0

SECTION: DAM 2 - STA. 34+75

0 50 100
SCALE IN FEET

2005 VIBRATING WIRE PIEZOMETER INSTALLATION:

D2-3475-R100B	ELEVATION	S/N
UPPER TAILINGS	1174.9	83359
MIDDLE TAILINGS	1161.9	83351
LOWER TAILINGS	1155.9	83357
UPPER CLAY	1137.9	83356
LOWER CLAY	1127.9	83349
TILL	1119.9	83354

CROSS SECTION SURFACE DEVELOPED FROM 2007 FLYOVER.

LEGEND

NOTE:

- - -?- - - UNAVAILABLE INFORMATION FOR ACCURATE CONTACT INTERPRETATION

STRATIGRAPHIC CONTACTS BETWEEN FOUNDATION SOILS ARE BASED ON INTERPRETATION BETWEEN BORINGS. CONTACTS BETWEEN INTERNAL DAM FILL ZONES ARE BASED ON INTERPRETATION BETWEEN BORINGS AND CONSTRUCTION RECORDS INFORMATION, WHERE AVAILABLE.

CPT CONE BEARING PRESSURE VS. ELEVATION

INVESTIGATIVE BORING

PIEZOMETRIC LEVEL (10/11/05)

3F-P2 PIEZOMETER IDENTIFIER

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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CLIENT	7/15						
BID							
CONSTRUCTION							
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MINNEAPOLIS, MN.
55435-4803
Ph: 1-800-632-2277
Fax: (952) 832-2601
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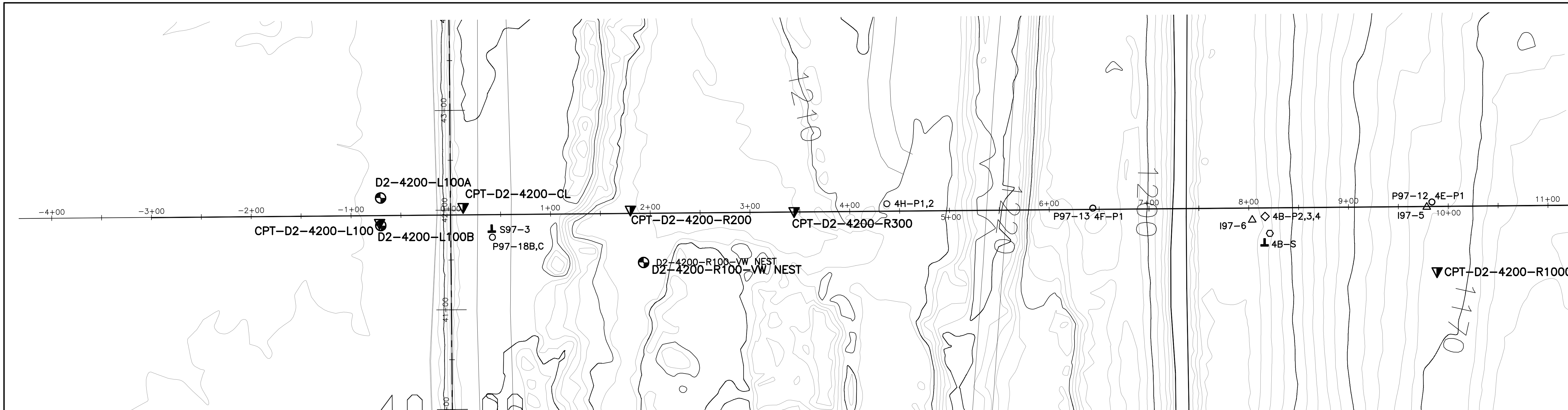
Scale	AS SHOWN
Date	7/15/09
Drawn	GSJ
Checked	ATG
Designed	ATG
Approved	ATG

NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

DAM 2 - STA. 34+75
CROSS SECTION OF EXISTING CONDITIONS

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-08
REV. No. A



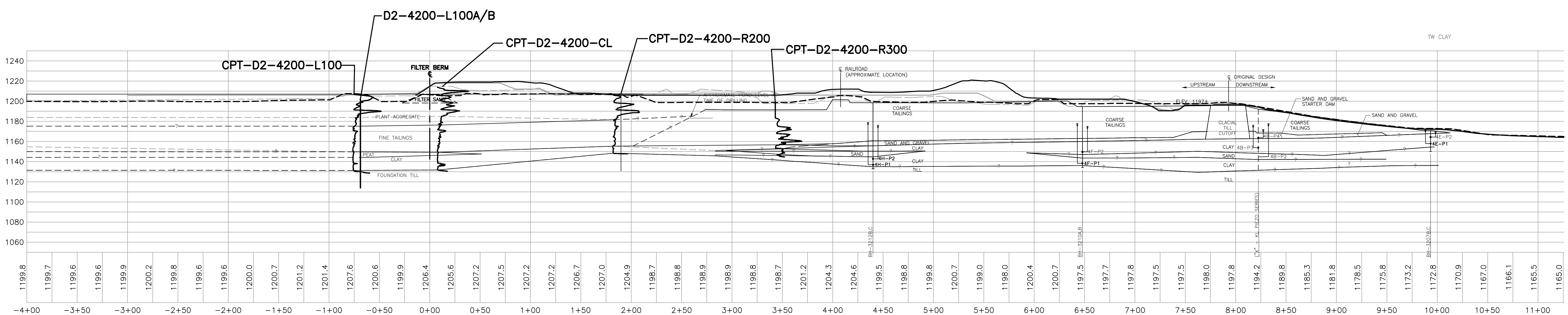
PLAN: DAM 2 – STA. 42+00 (1 / G-07)

0 50 100
SCALE IN FEET

LEGEND:

PREVIOUSLY INSTALLED INSTRUMENTS:
- PNEUMATIC PIEZOMETER
- CASAGRANDE PIEZOMETER
- INCLINOMETER
- RELIEF WELL
- SETTLEMENT PLATE

2005 INVESTIGATION:
- BORING LOCATION
- CPT LOCATION



SECTION: DAM 2 – STA. 42+00 (1 / G-07)

0 50 100
SCALE IN FEET

NOTE: CROSS SECTION SURFACE DEVELOPED FROM 2007 FLYOVER.

2007 VIBRATING WIRE PIEZOMETER INSTALLATION:

D2-4200-R100	ELEVATION	S/N
FINE TAILINGS	1161	29430
PEAT	1147	29431
LACUSTRINE CLAY	1137	29432
TILL	1132	29433

LEGEND

– – –?– – – UNAVAILABLE INFORMATION FOR ACCURATE CONTACT INTERPRETATION

STRATIGRAPHIC CONTACTS BETWEEN FOUNDATION SOILS ARE BASED ON INTERPRETATION BETWEEN BORINGS. CONTACTS BETWEEN INTERNAL DAM FILL ZONES ARE BASED ON INTERPRETATION BETWEEN BORINGS AND CONSTRUCTION RECORDS INFORMATION, WHERE AVAILABLE.

CPT CONE BEARING PRESSURE VS. ELEVATION

INVESTIGATIVE BORING
PIEZOMETRIC LEVEL (10/11/05)
3F-P2 PIEZOMETER IDENTIFIER

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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DATE ____ REG. NO. ____

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CLIENT	7/15						
BID							
CONSTRUCTION							
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NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

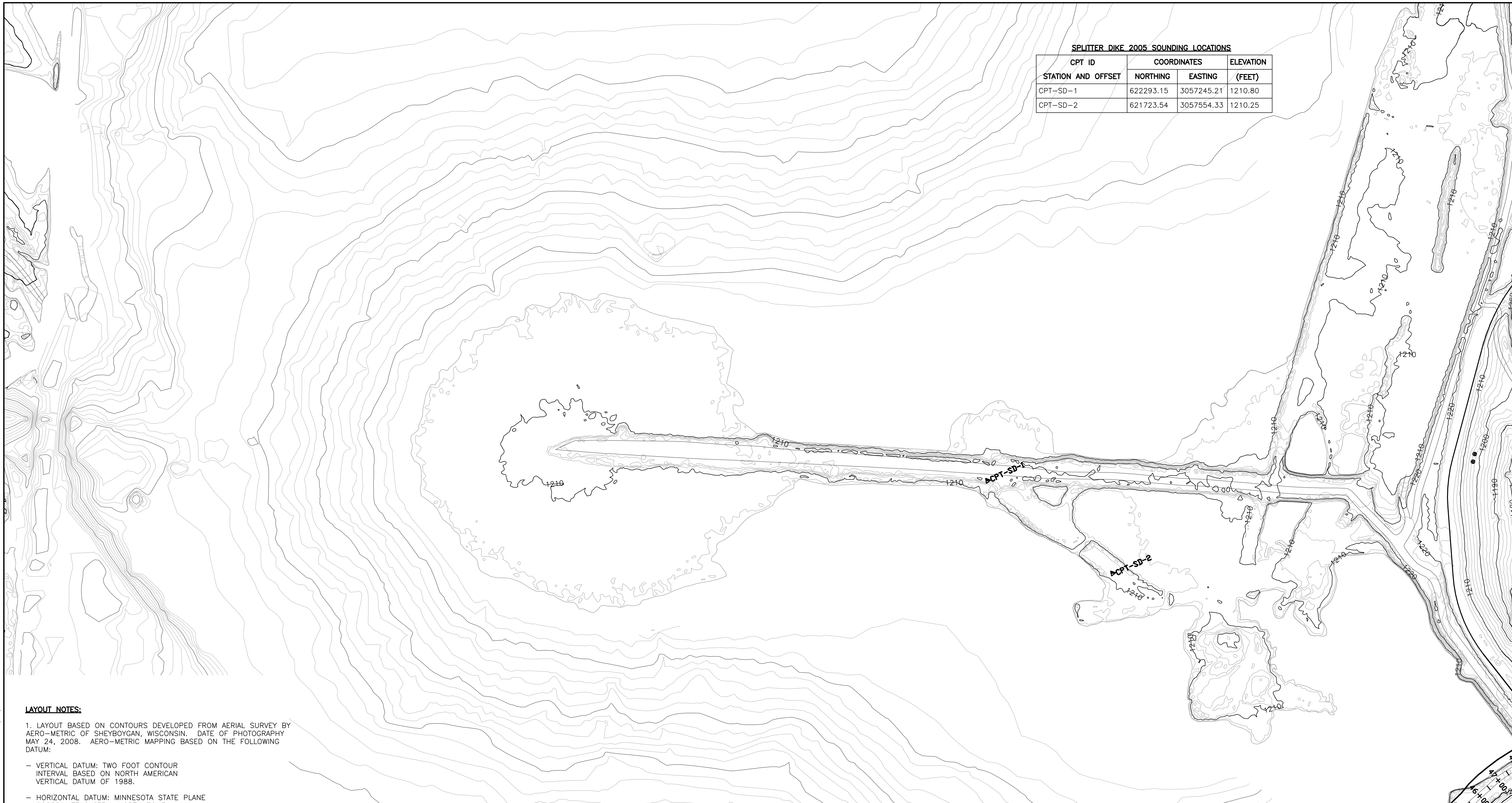
DAM 2 – STA. 42+00
CROSS SECTION OF EXISTING CONDITIONS

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-09
REV. No. A

Xrefs in Drawing - M:\cad\N_shore\2338_086\Geotechnical\xref\19667_2.DWG M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-10.DWG Plot at 1000 07/13/2009 14:33:30

SPLITTER DIKE 2005 SOUNDING LOCATIONS

CPT ID	COORDINATES		ELEVATION
STATION AND OFFSET	NORTHING	EASTING	(FEET)
CPT-SD-1	622293.15	3057245.21	1210.80
CPT-SD-2	621723.54	3057554.33	1210.25



LAYOUT NOTES:

1. LAYOUT BASED ON CONTOURS DEVELOPED FROM AERIAL SURVEY BY AERO-METRIC OF SHEYBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY MAY 24, 2008. AERO-METRIC MAPPING BASED ON THE FOLLOWING DATUM:

- VERTICAL DATUM: TWO FOOT CONTOUR INTERVAL BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988.
- HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

LEGEND:

▼ CPT SOUNDING LOCATION

1 PLAN: SPLITTER DIKE

0 200 400
SCALE IN FEET

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PRINTED NAME ______
DATE ______ REG. NO. ______

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CLIENT	7/15						
BID							
CONSTRUCTION							
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Scale	AS SHOWN
Date	7/15/09
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Checked	MLK2
Designed	ATG
Approved	ATG

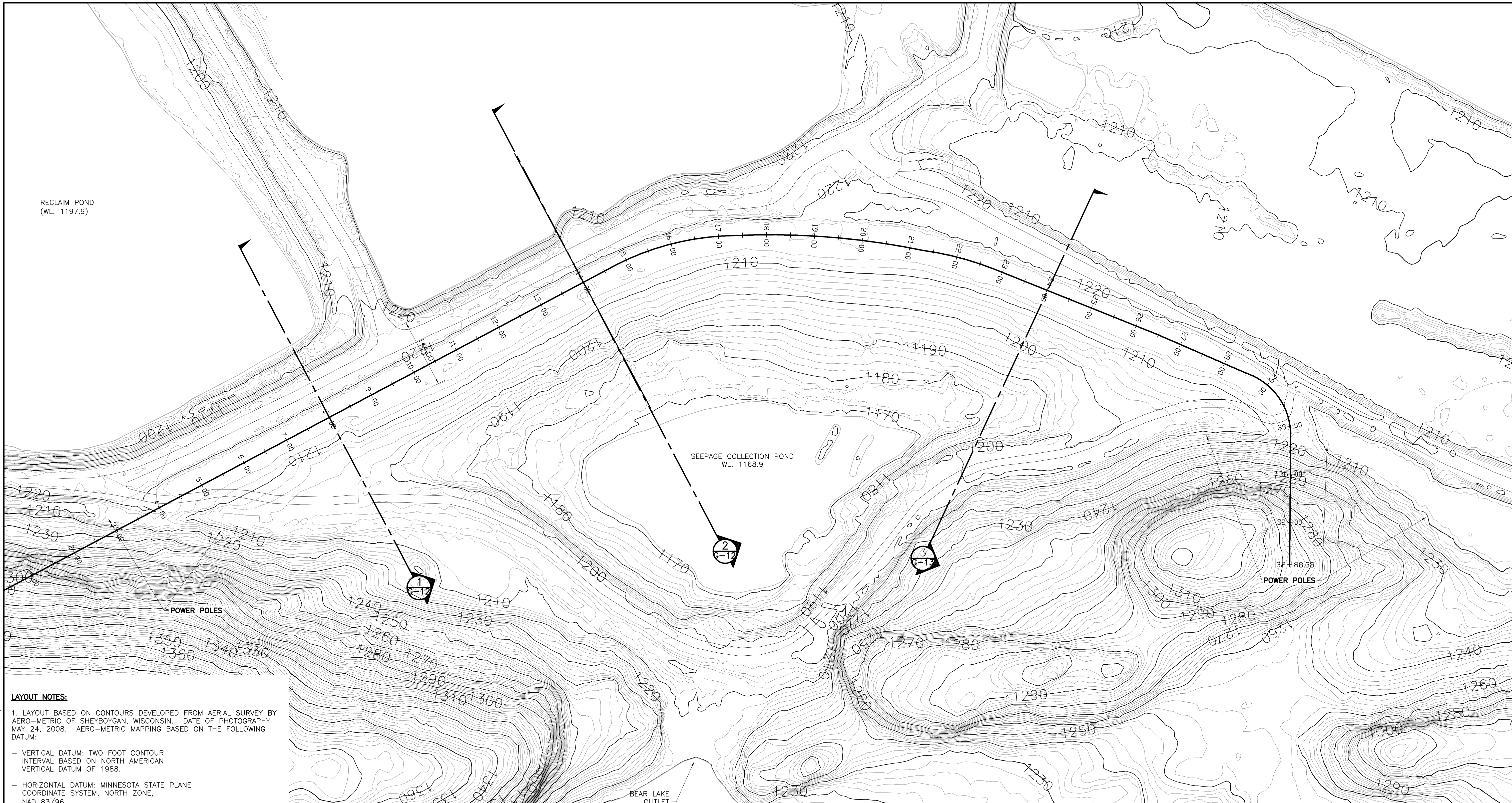
NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

SPLITTER DIKE
PLAN VIEW WITH 2005 CPT LOCATIONS

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-10
REV. No. A

Xrefs in Drawing – M:\cad\N_shore\2338_086\2008 Lidar\ACAD-Nshr_MP7 2008.dwg
gsj M:\cad\N_shore\2338_086\Geotechnical\2009 update\G-11.DWG Plot at 1000 07/13/2009 14:31:19



LAYOUT NOTES:

1. LAYOUT BASED ON CONTOURS DEVELOPED FROM AERIAL SURVEY BY AERO-METRIC OF SHEYBOYGAN, WISCONSIN. DATE OF PHOTOGRAPHY MAY 24, 2008. AERO-METRIC MAPPING BASED ON THE FOLLOWING DATUM:

– VERTICAL DATUM: TWO FOOT CONTOUR INTERVAL BASED ON NORTH AMERICAN VERTICAL DATUM OF 1988.

– HORIZONTAL DATUM: MINNESOTA STATE PLANE COORDINATE SYSTEM, NORTH ZONE, NAD 83/96

1 PLAN: DAM 5

0 100 200
SCALE IN FEET

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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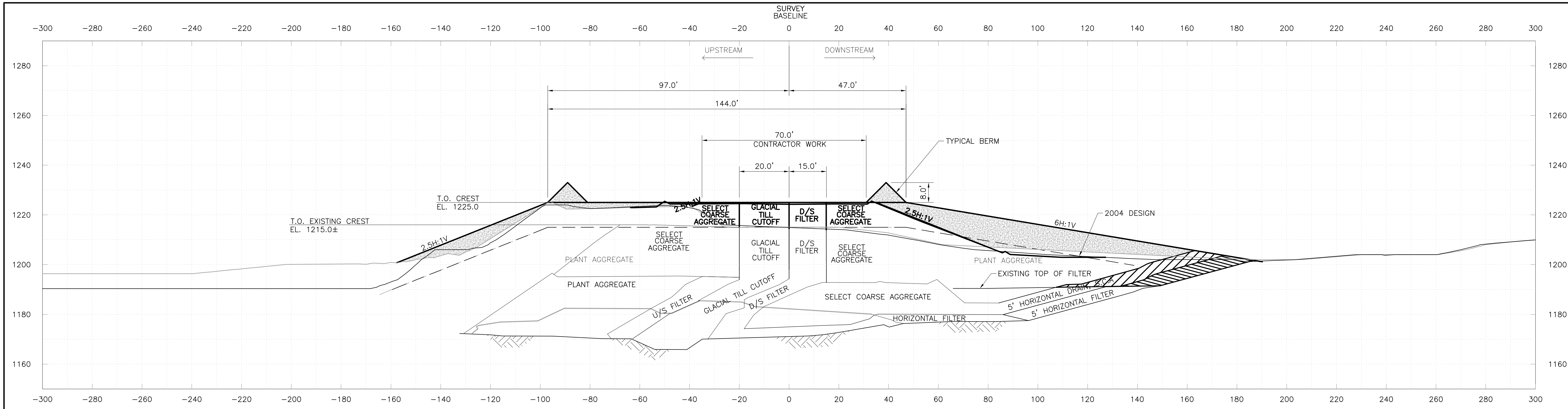
SILVER BAY, MINNESOTA

MILEPOST 7 TAILING BASIN
GEOTECHNICAL EVALUATION

DAM 5
PLAN VIEW

BARR PROJECT No. **23/38-086**
CLIENT PROJECT No.
DWG. No. G-11
REV. No. A

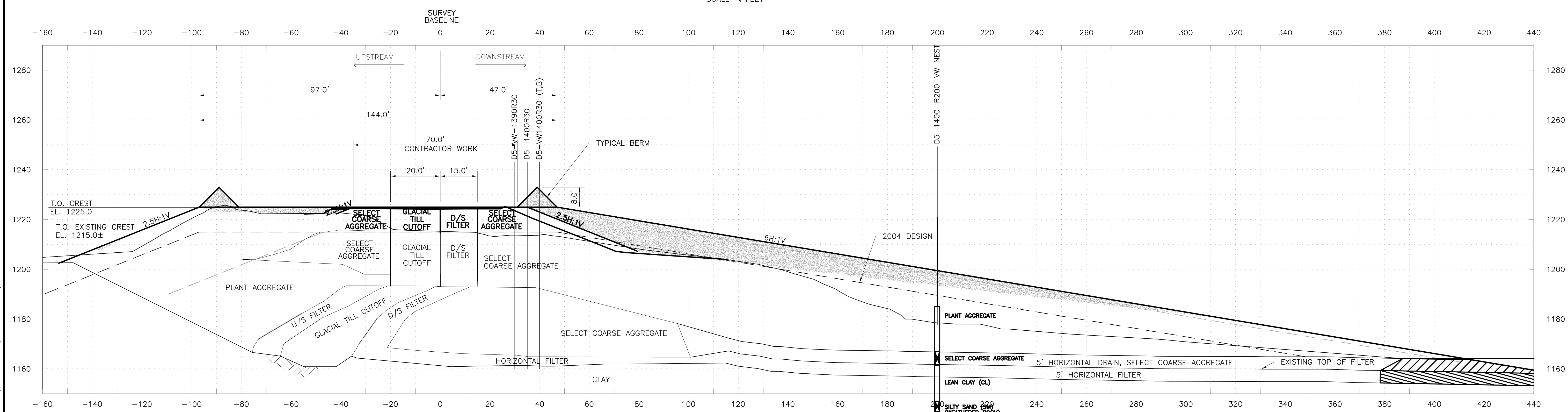


1 SECTION: STATION 8+00

G-10

0 20 40

SCALE IN FEET



2 SECTION: STATION 14+00

G-10

0 20 40

SCALE IN FEET

2007 VIBRATING WIRE PIEZOMETER INSTALLATION:

D1-3500-R100A	ELEVATION	S/N
FILTER MATERIAL	1165	29434
LEAN CLAY	1159	29435
LEAN CLAY	1150	29436

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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BID							
CONSTRUCTION							

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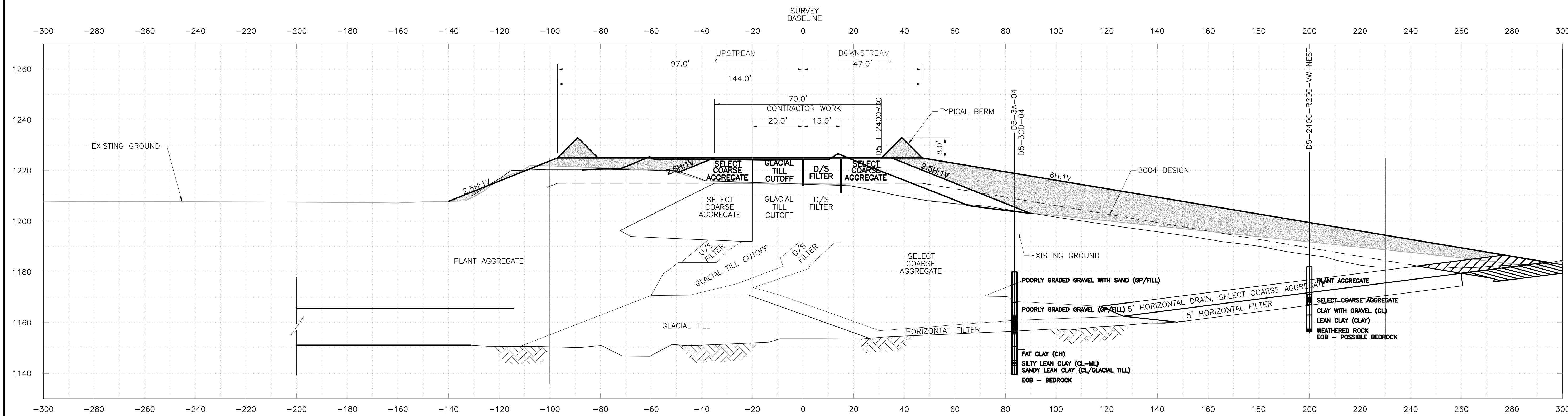
SILVER BAY, MINNESOTA

MILEPOST 7 TAILINGS BASIN
GEOTECHNICAL EVALUATION
DAM 5 – TYPICAL DESIGN SECTIONS 8+00 AND 14+00

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-12
REV. No. A



1 SECTION: STATION 24+00
G-10
0 20 40
SCALE IN FEET

2007 VIBRATING WIRE PIEZOMETER INSTALLATION:

D5-2400-R200	ELEVATION	S/N
FILTER MATERIAL	1169	29437
LEAN CLAY W/ GRAVEL	1166	29438
LEAN CLAY	1160	29439

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

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PRINTED NAME ______
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CLIENT	7/15						
BID							
CONSTRUCTION							
	DATE RELEASED						

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Scale	AS SHOWN
Date	7/15/09
Drawn	GSJ
Checked	ATG
Designed	ATG
Approved	ATG

NORTHSHORE MINING COMPANY
SILVER BAY, MINNESOTA

MILEPOST 7 TAILINGS BASIN
GEOTECHNICAL EVALUATION
DAM 5 TYPICAL DESIGN SECTION
24+00

BARR PROJECT No. 23/38-086
CLIENT PROJECT No.
DWG. No. G-13
REV. No. A

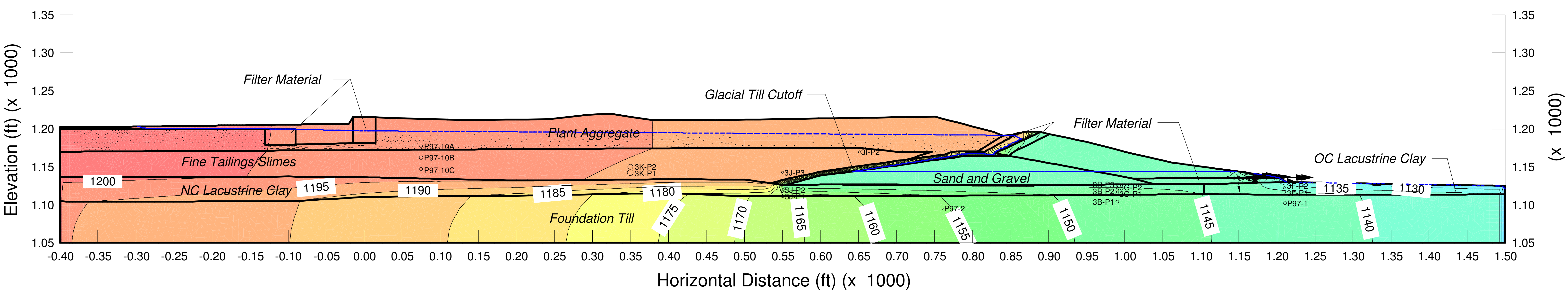
Appendix B

Results of Seepage Analyses
Dam 1

Dam 1

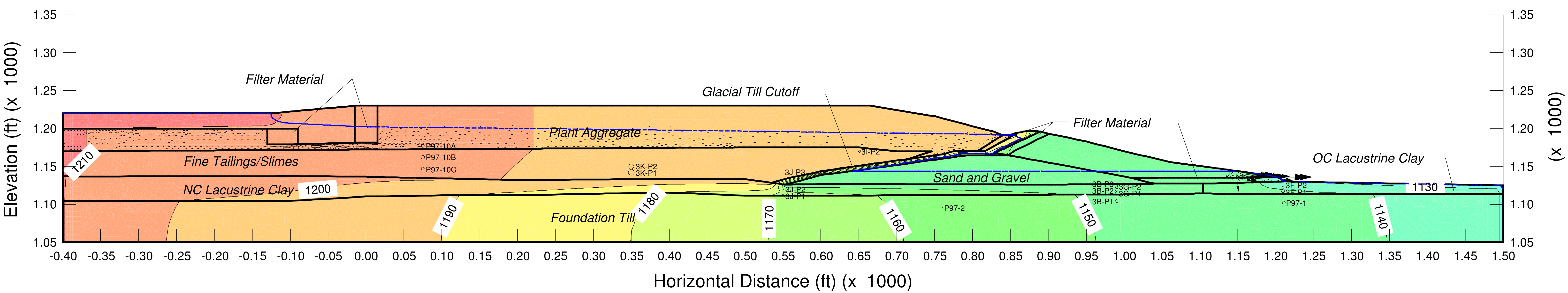
Northshore Mining, Dam 1, Sta. 28+40, Seepage Analysis
Existing Geometry (El. 1215)
File Name: D1_S2840_E1215_SEEP.gsz
Last Saved Date: 12/3/2008

Contours are Total Head [feet]



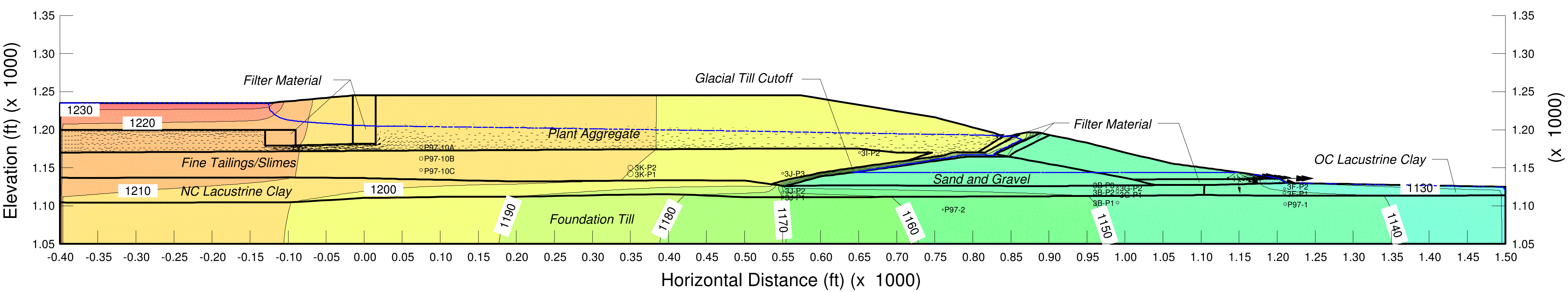
Northshore Mining, Dam 1, Sta. 28+40, Seepage Analysis
Intermediate Geometry (El. 1230)
File Name: D1_S2840_E1230_SEEP.gsz
Last Saved Date: 12/3/2008

Contours are Total Head [feet]



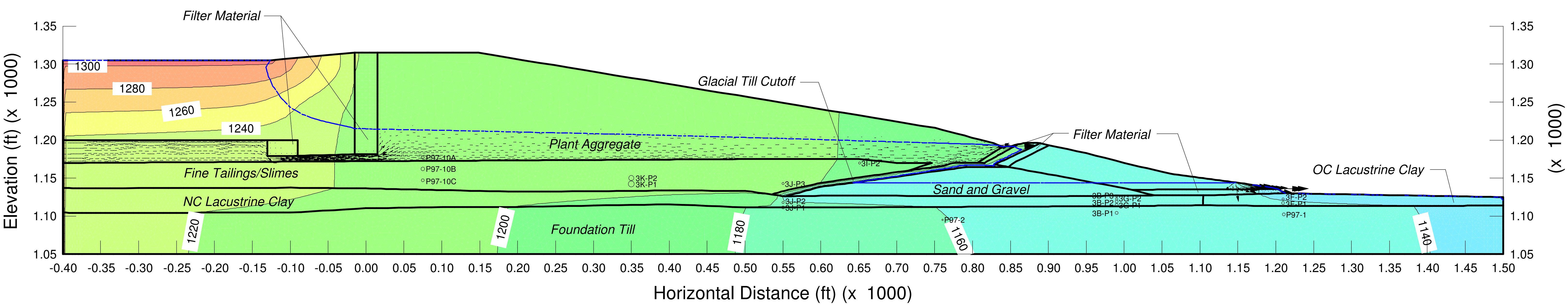
Northshore Mining, Dam 1, Sta. 28+40, Seepage Analysis
Intermediate Geometry (El. 1245)
File Name: D1_S2840_E1245_SEEP.gsz
Last Saved Date: 12/3/2008

Contours are Total Head [feet]



Northshore Mining, Dam 1, Sta. 28+40, Seepage Analysis
Ultimate Geometry (El. 1315)
File Name: D1_S2840_E1315_SEEP.gsz
Last Saved Date: 12/3/2008

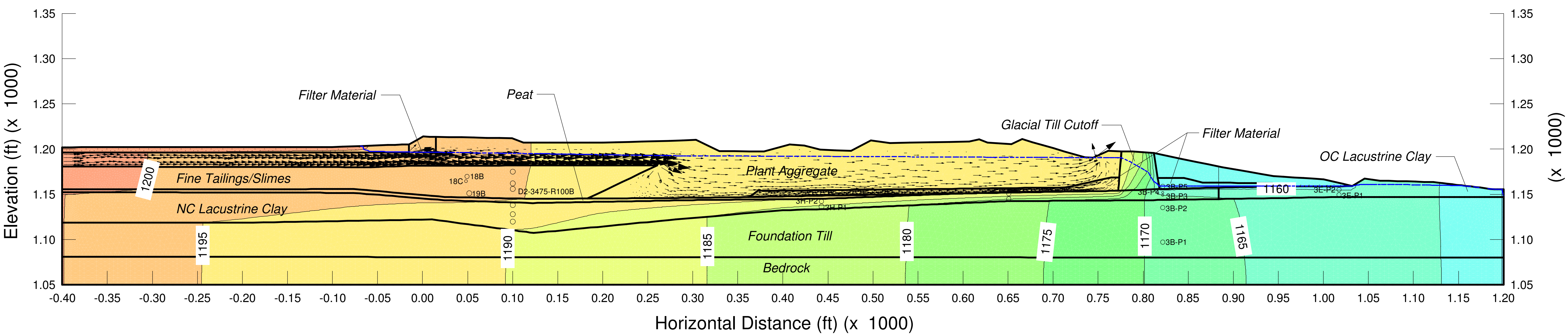
Contours are Total Head [feet]



Dam 2

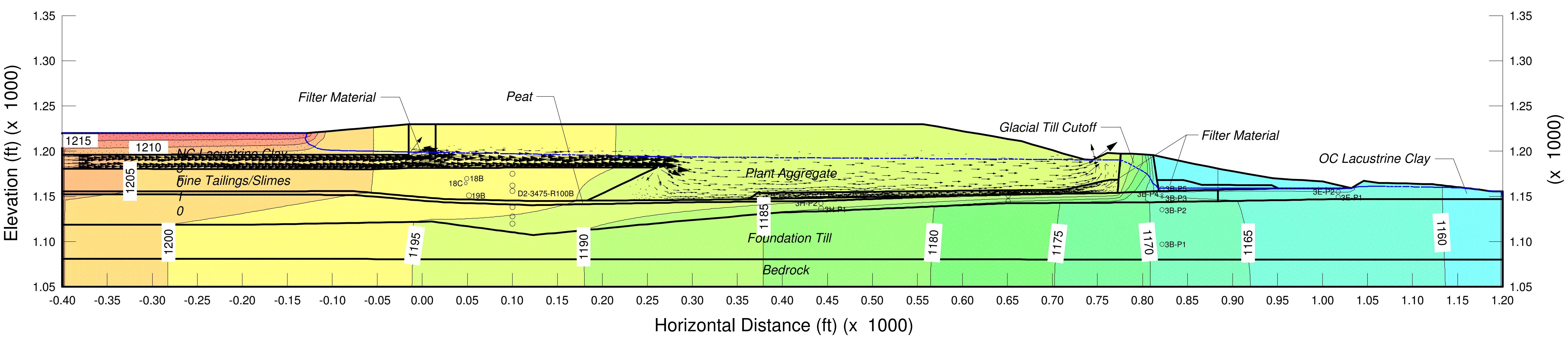
Northshore Mining, Dam 2, Sta. 34+75, Seepage Analysis
Existing Geometry (El. 1215)
File Name: D2_S3475_E1215_SEEP.gsz
Last Saved Date: 12/3/2008

Contours are Total Head [feet]



Northshore Mining, Dam 2, Sta. 34+75, Seepage Analysis
Intermediate Geometry (El. 1230)
File Name: D2_S3475_E1230_SEEP.gsz
Last Saved Date: 12/3/2008

Contours are Total Head [feet]



Northshore Mining, Dam 2, Sta. 34+75, Seepage Analysis
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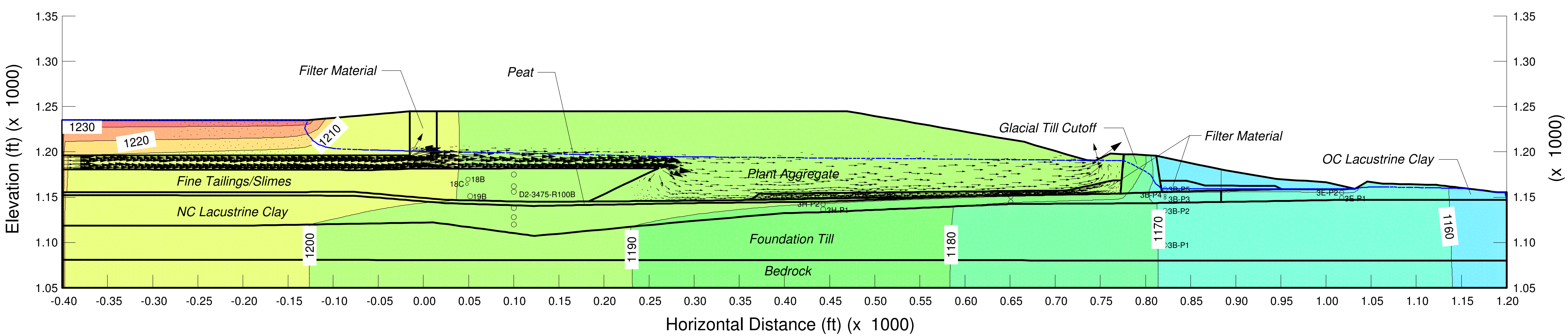
Contours are Total Head [feet]



Northshore Mining, Dam 2, Sta. 34+75, Seepage Analysis
Ultimate Geometry (El. 1315)
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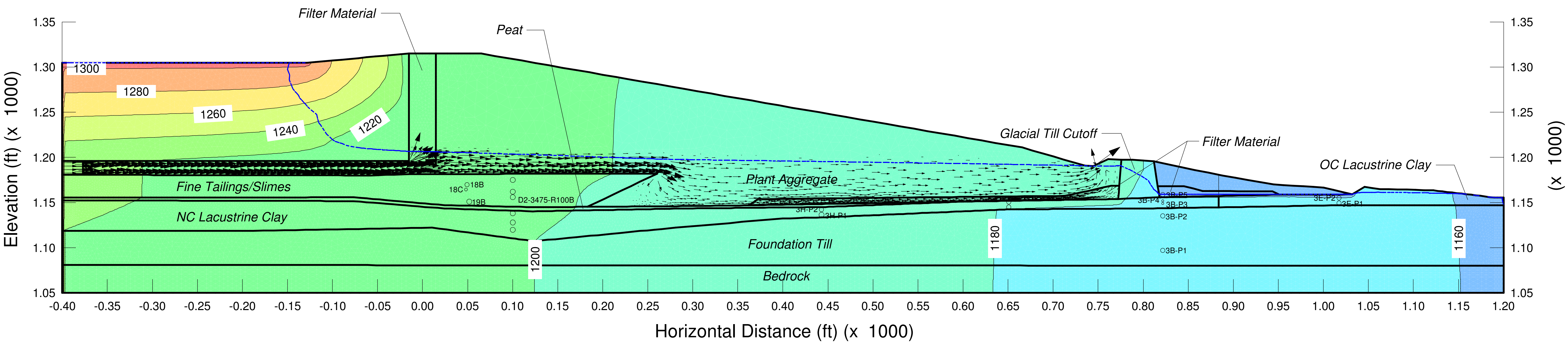
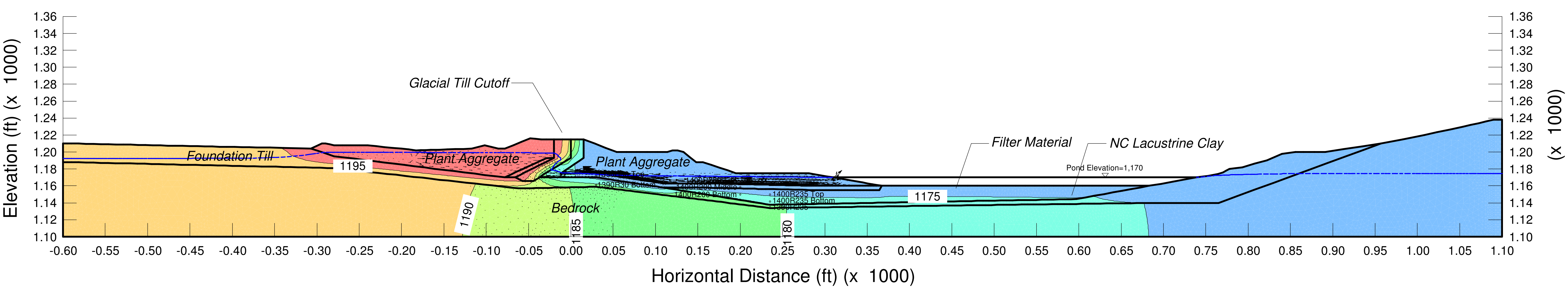
Contours are Total Head [feet]



Dam 5

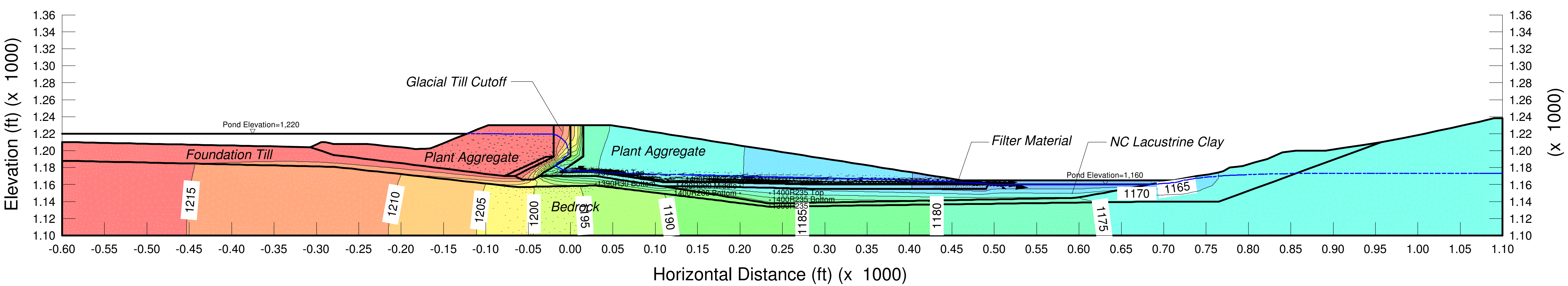
Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Existing Geometry (El. 1215)
File Name: D5_S1400_E1215_SEEP.gsz
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



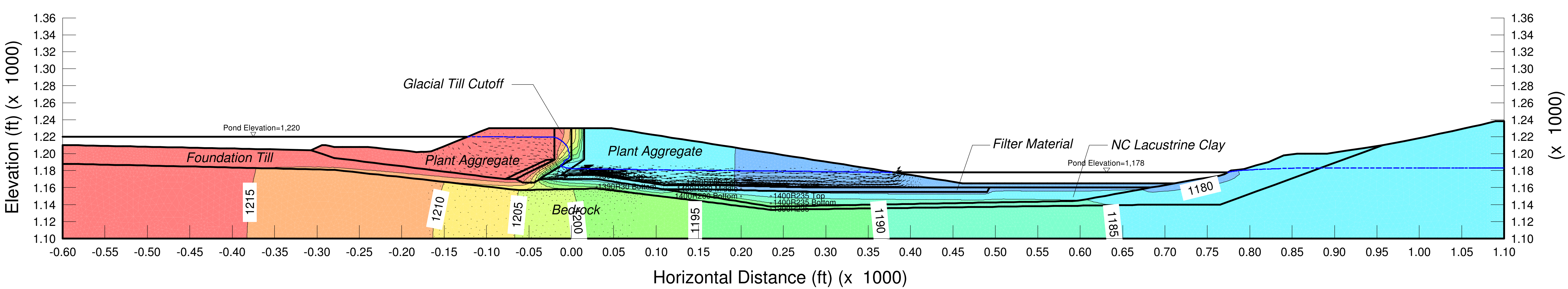
Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Intermediate Geometry (El. 1230), Low Pond
_File Name: D5_S1400_E1230_Low_SEEP.gsz_
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



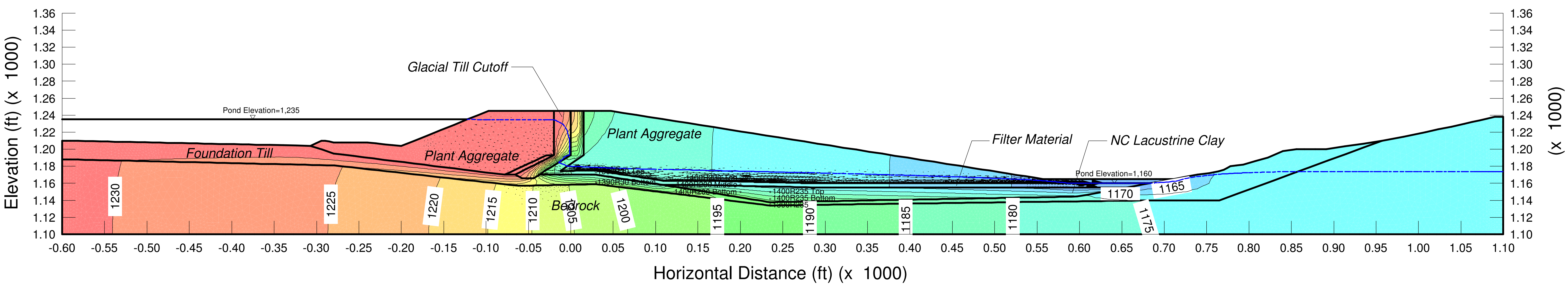
Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Intermediate Geometry (El. 1230), High Pond
File Name: D5_S1400_E1230_High_SEEP.gsz
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



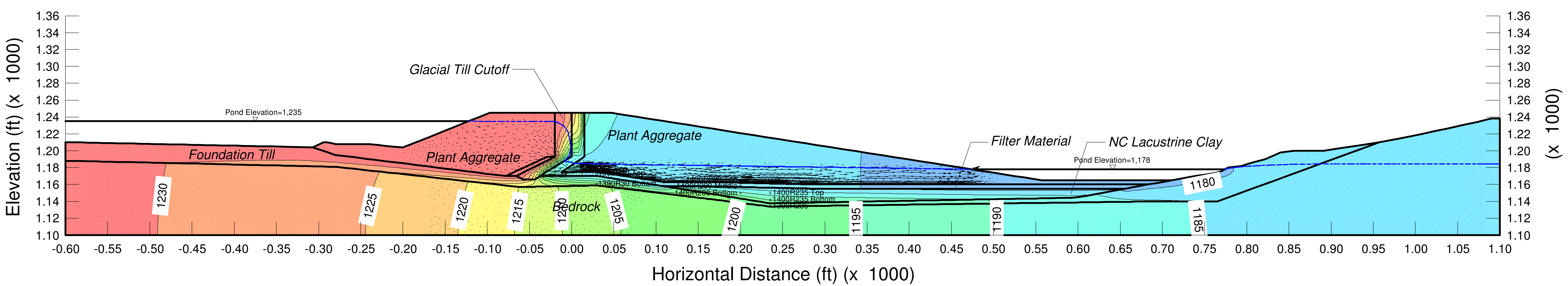
Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Intermediate Geometry (El. 1245), Low Pond
File Name: D5_S1400_E1245_Low.gsz
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



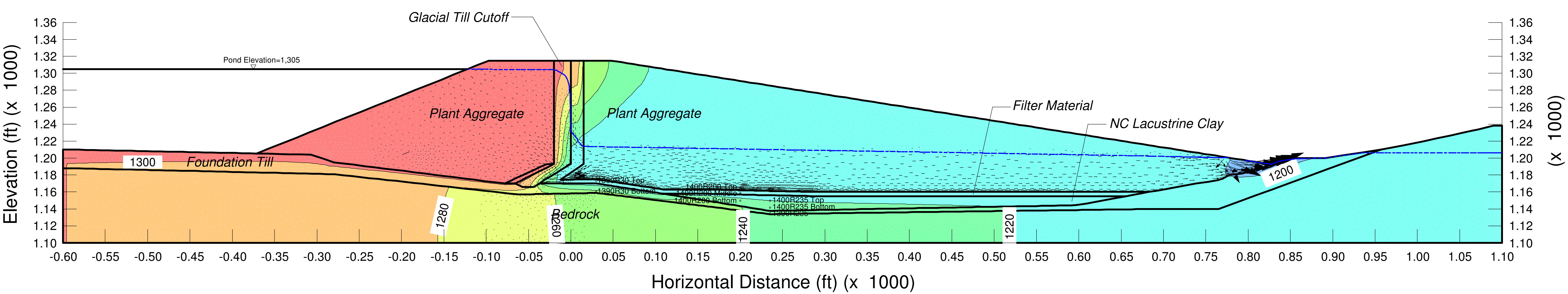
Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Intermediate Geometry (El. 1245), High Pond
File Name: D5_S1400_E1245_High.gsz
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



Northshore Mining, Dam 5, Sta. 14+00, Seepage Analysis
Ultimate Geometry (El. 1315)
File Name: D5_S1400_E1315_SEEP.gsz
Last Saved Date: 8/28/2008

Contours are Total Head [in feet]



Appendix C

Results of Slope Stability Analyses

Dam 1

Existing Geometry – Existing Conditions

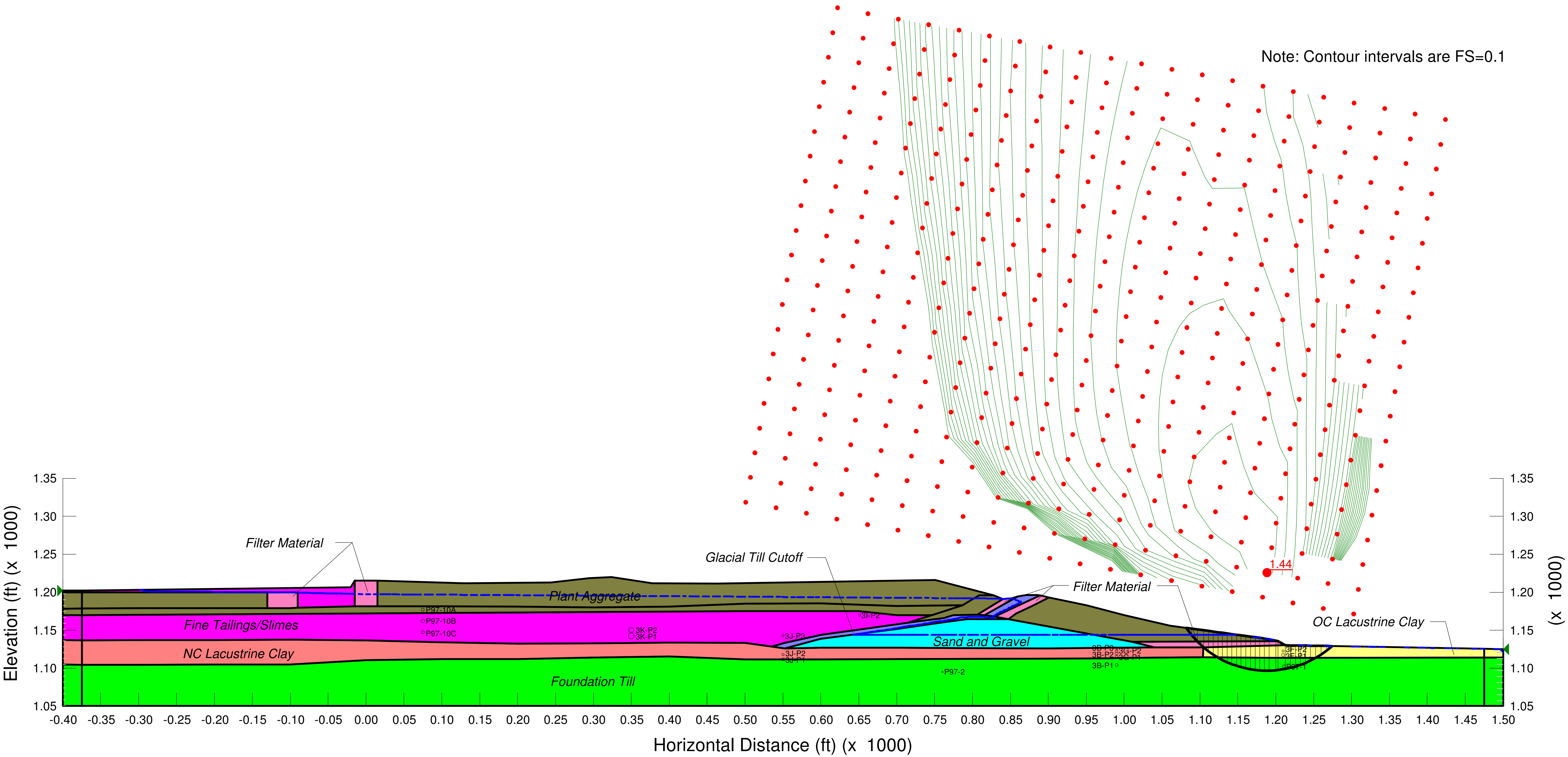
Proposed Geometry El. 1,230 feet

Proposed Geometry El. 1,245 feet

Proposed Geometry El. 1,315 feet

Existing Geometry – Existing Conditions

Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D1_S2840_E1215_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D1_S2840_E1215_USSA_LC5_FT2_FM3.gsz
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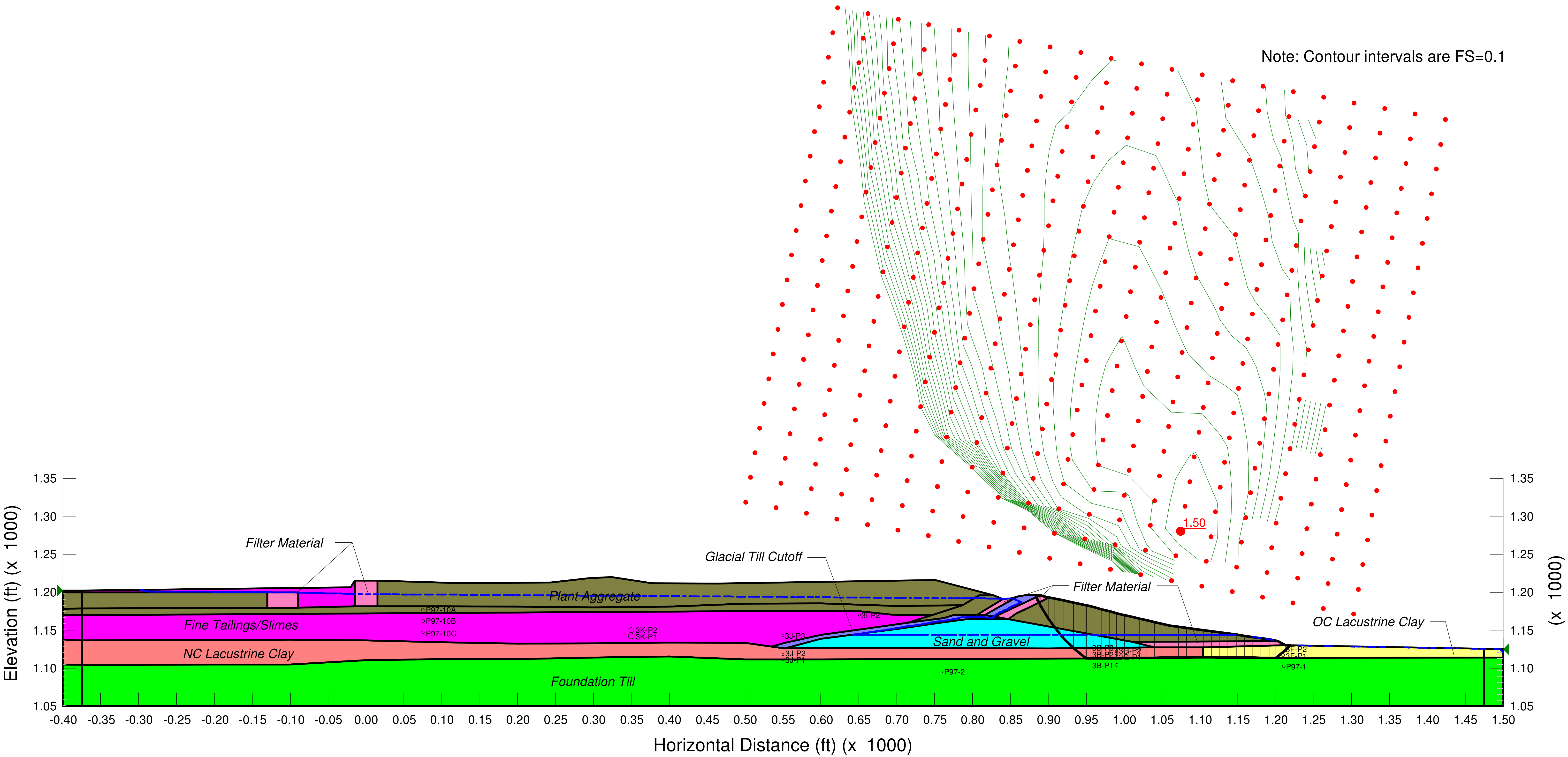
Factor of Safety: 1.50



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D1_S2840_E1215_USSA_LC6_FT2_FM1.gsz
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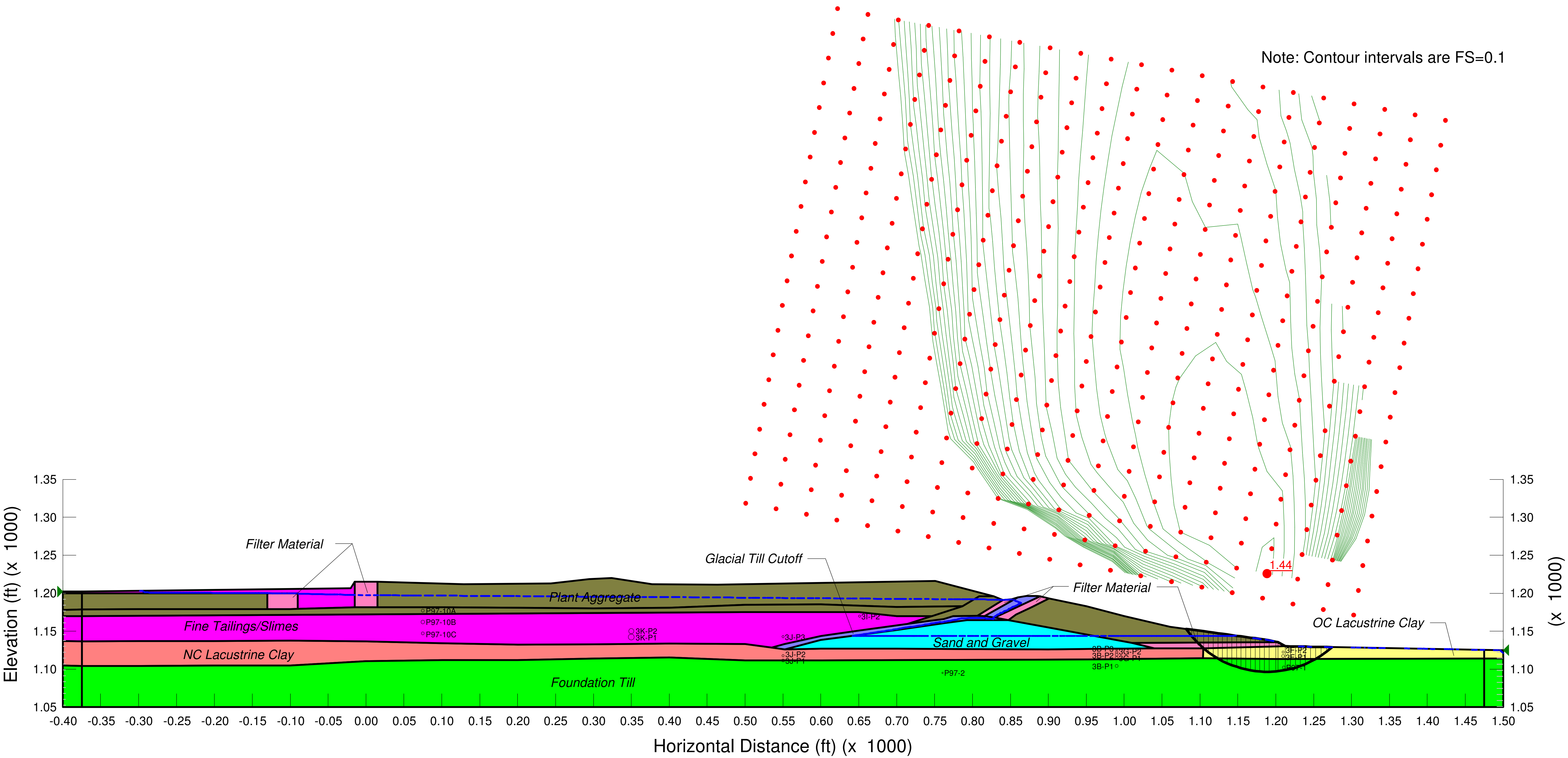
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.2, FM Block
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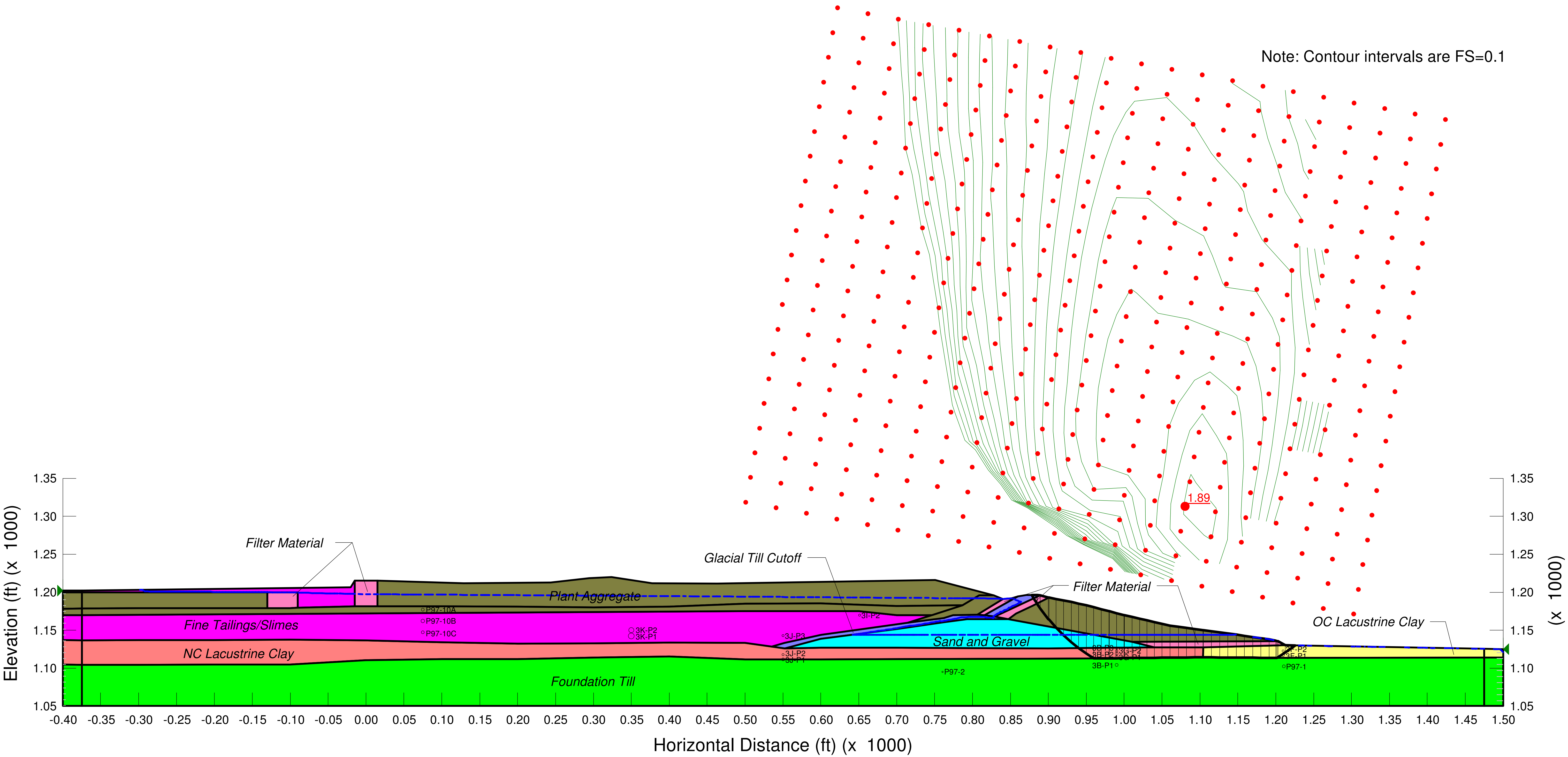
Last Saved Date: 6/19/2009
Factor of Safety: 1.89



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.2, FM Toe
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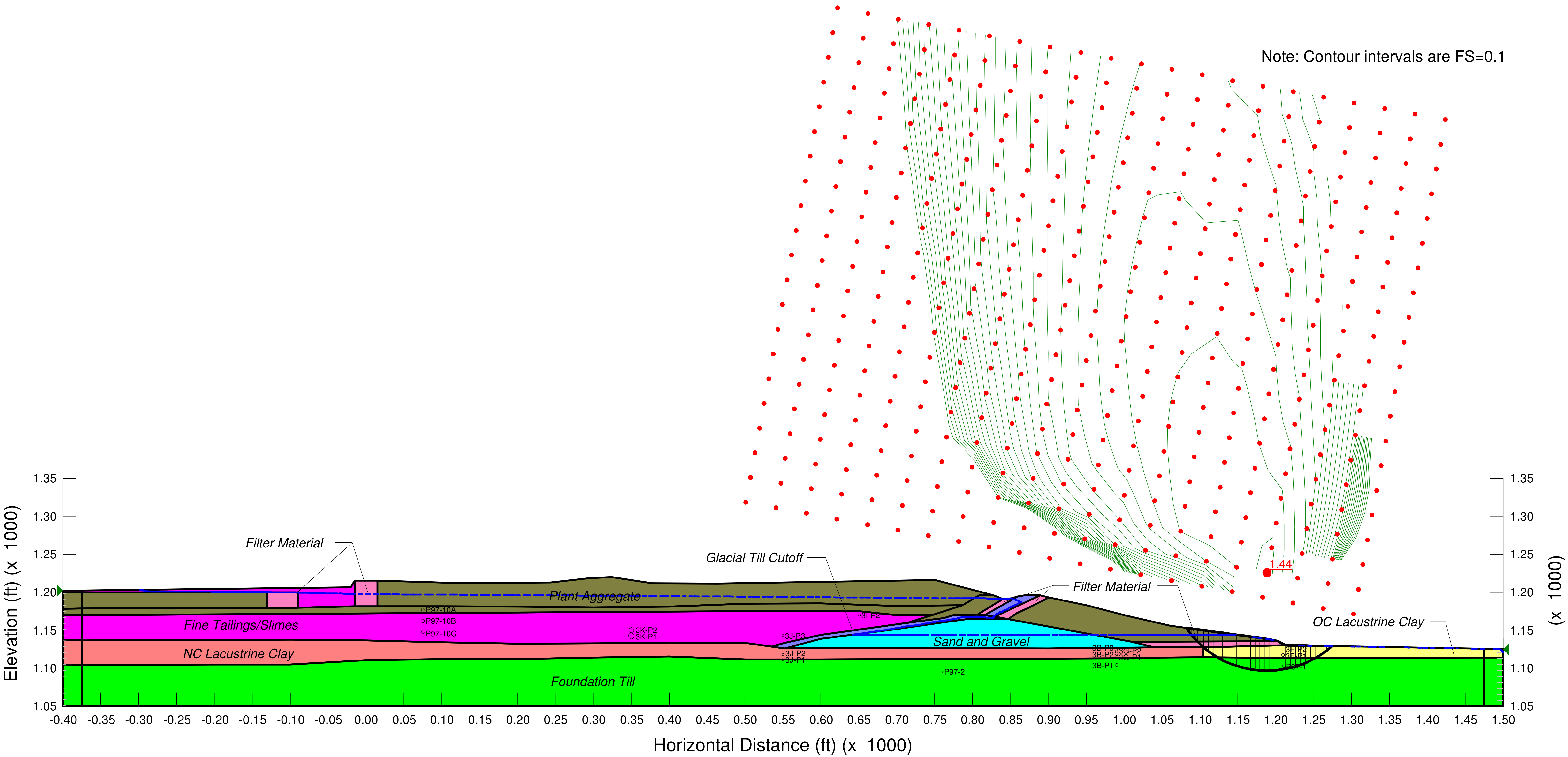
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.2, FM Block
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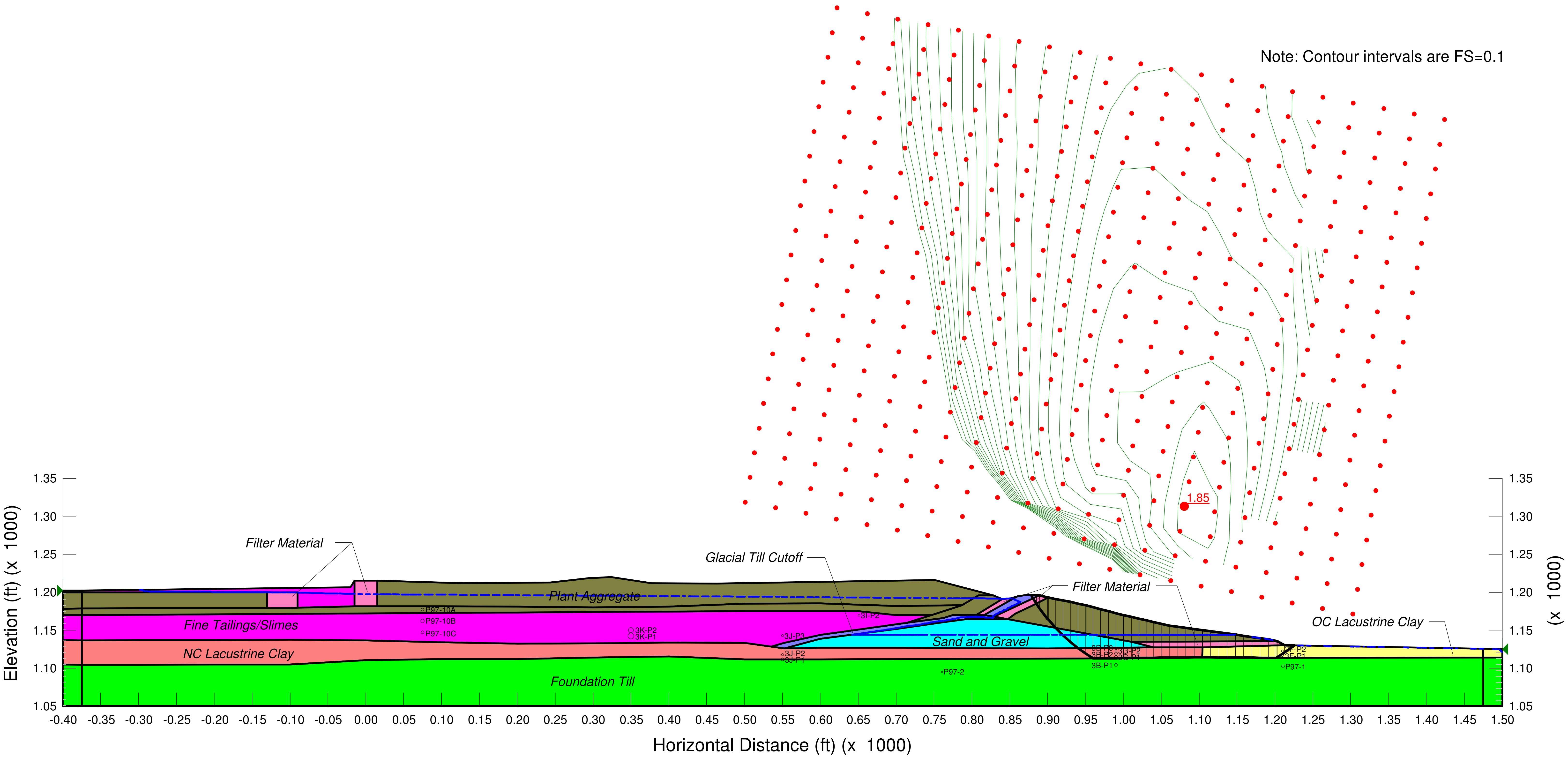
Factor of Safety: 1.85



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.2, FM Toe
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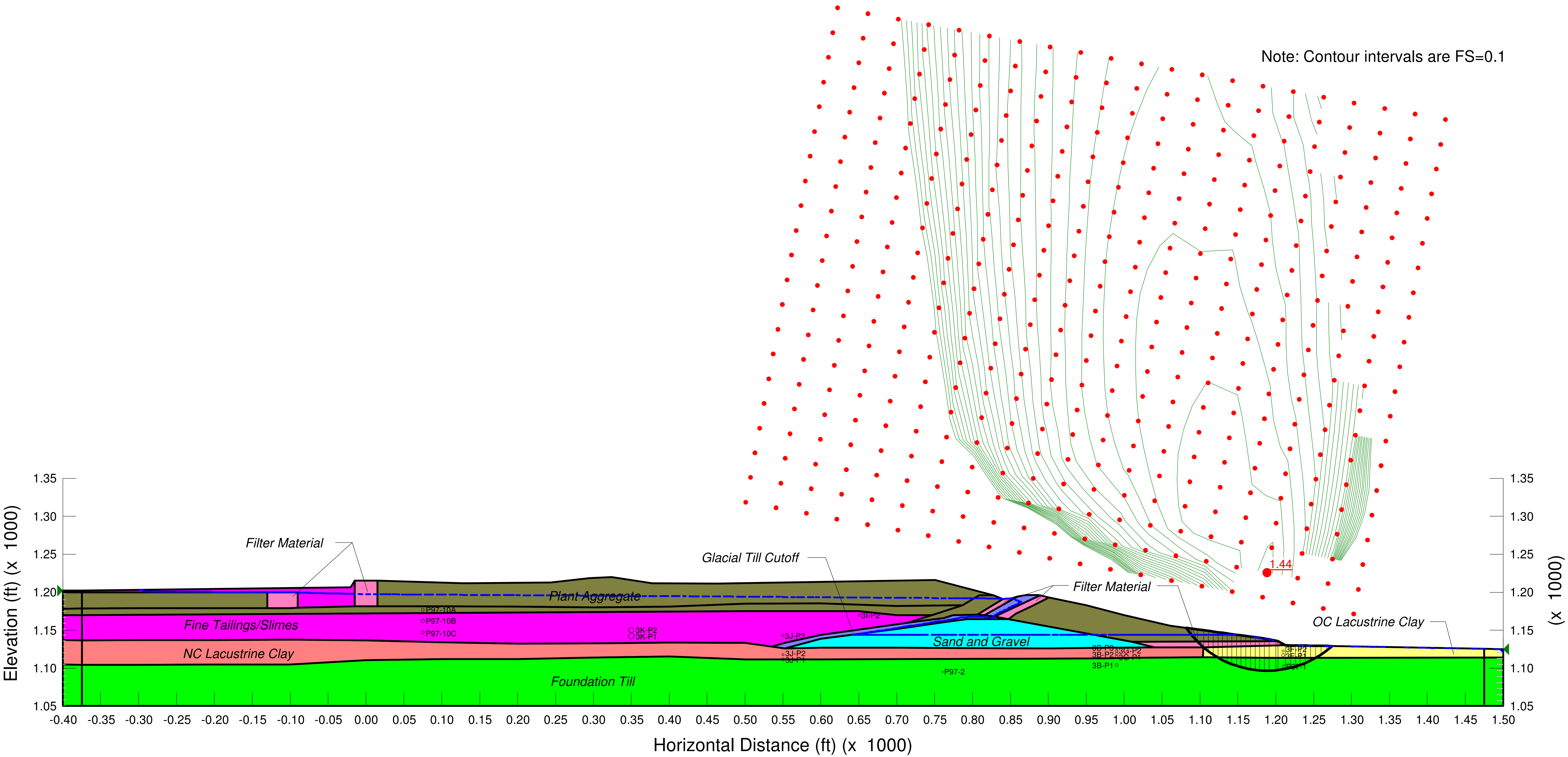
Last Saved Date: 6/19/2009
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.2, FM Block
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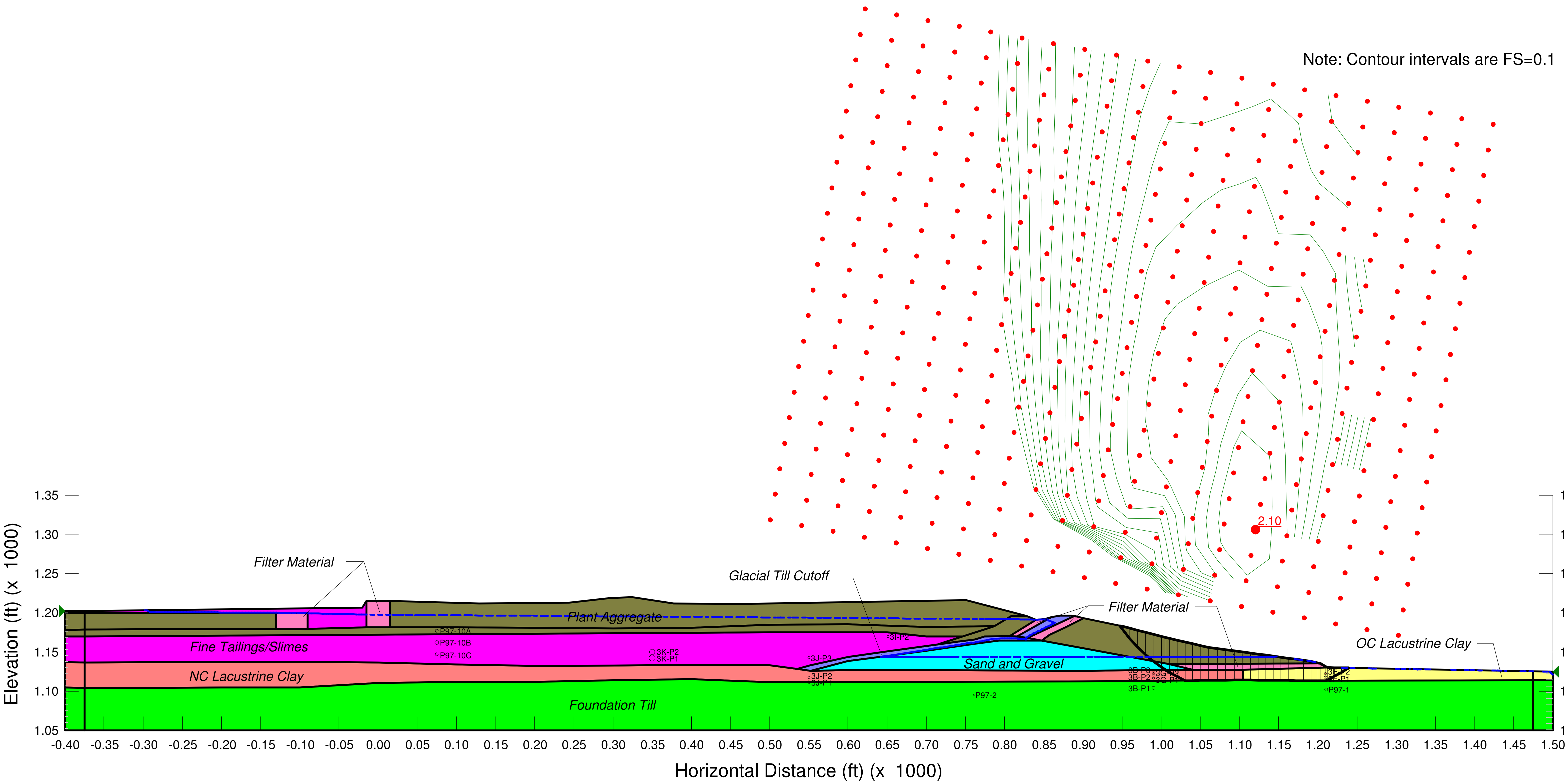
Factor of Safety: 2.10



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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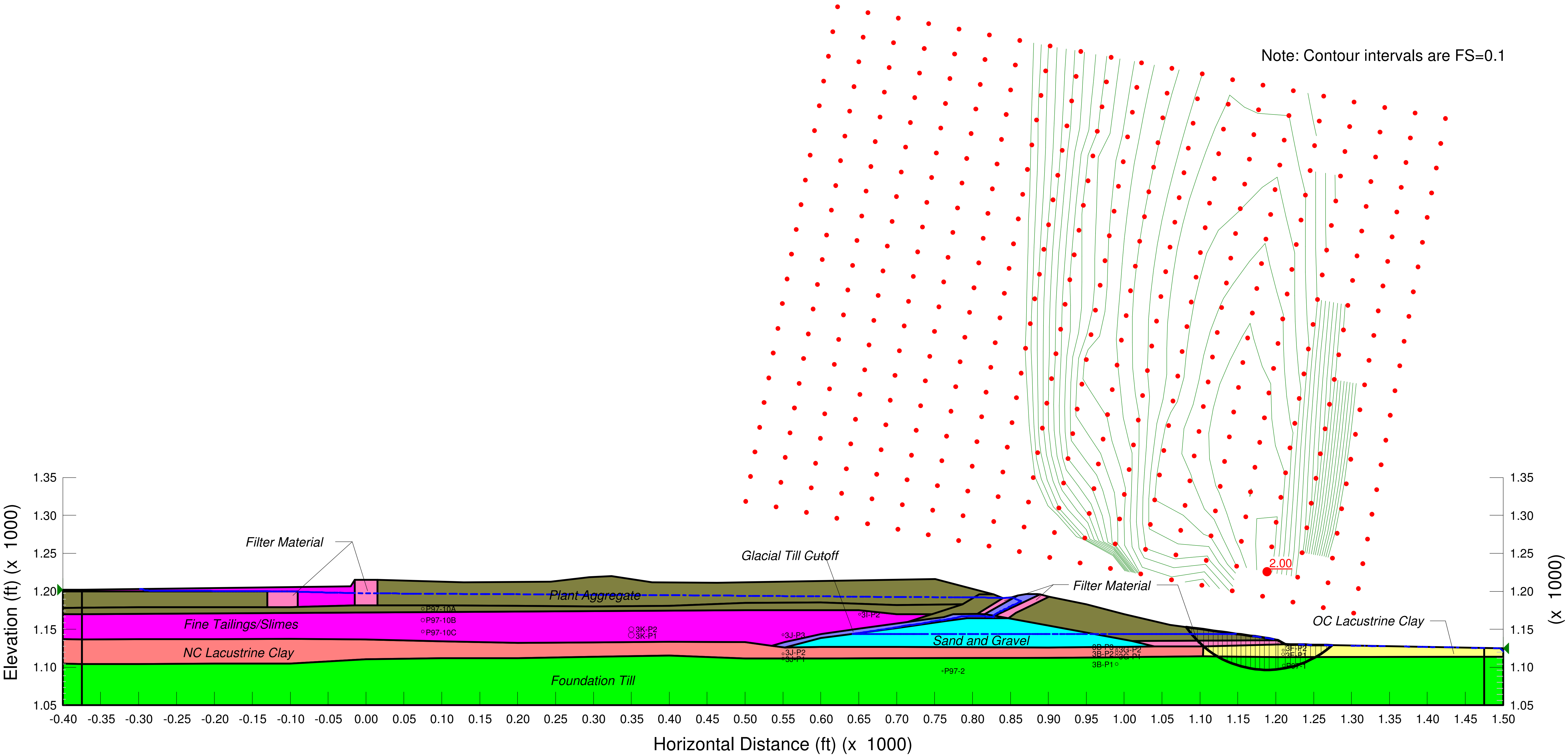
File Name: D1_S2840_E1215_ESSA_LC1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.00



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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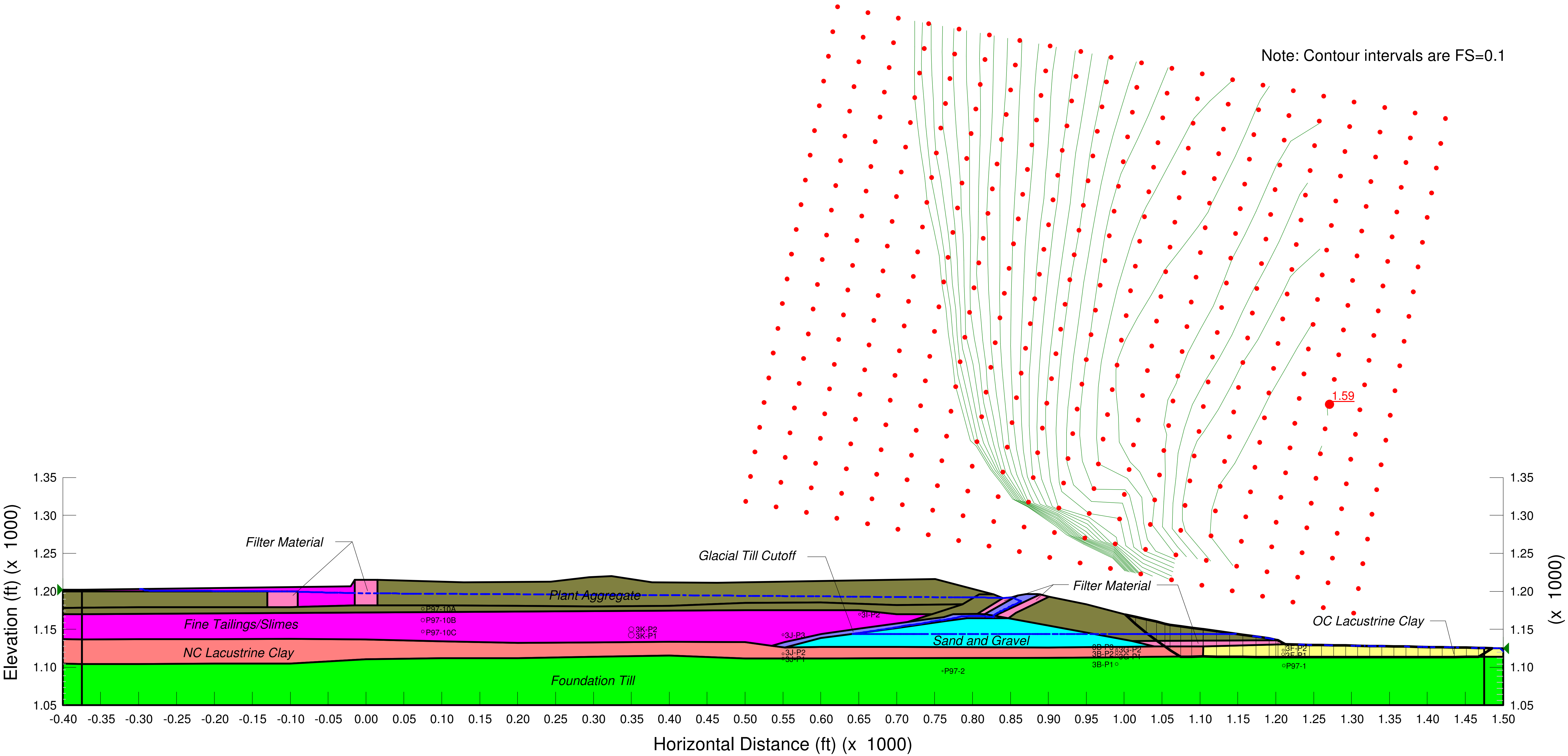
Last Saved Date: 11/17/2008
Factor of Safety: 1.59



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC DSS Average, FM Toe
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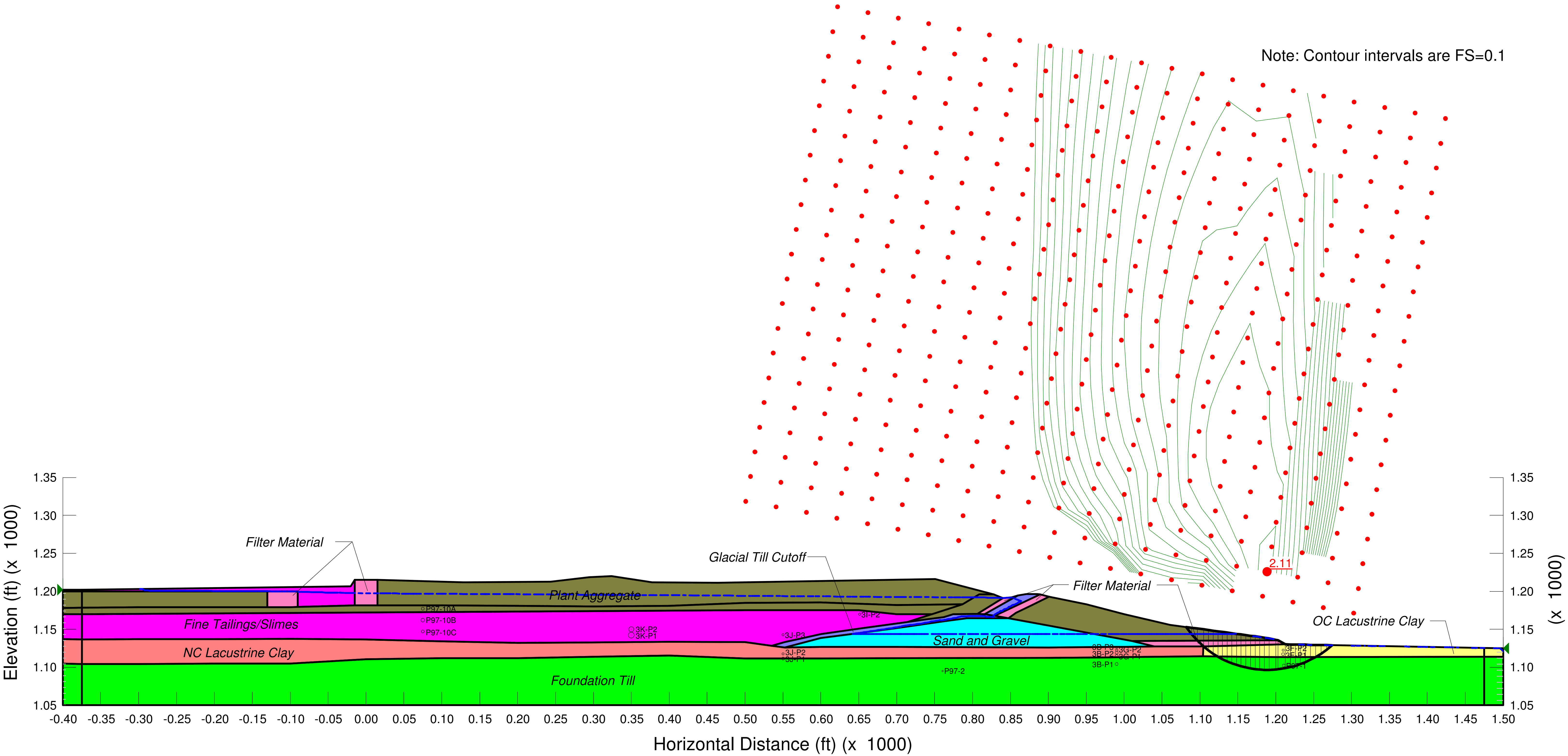
Last Saved Date: 11/17/2008
Factor of Safety: 2.11



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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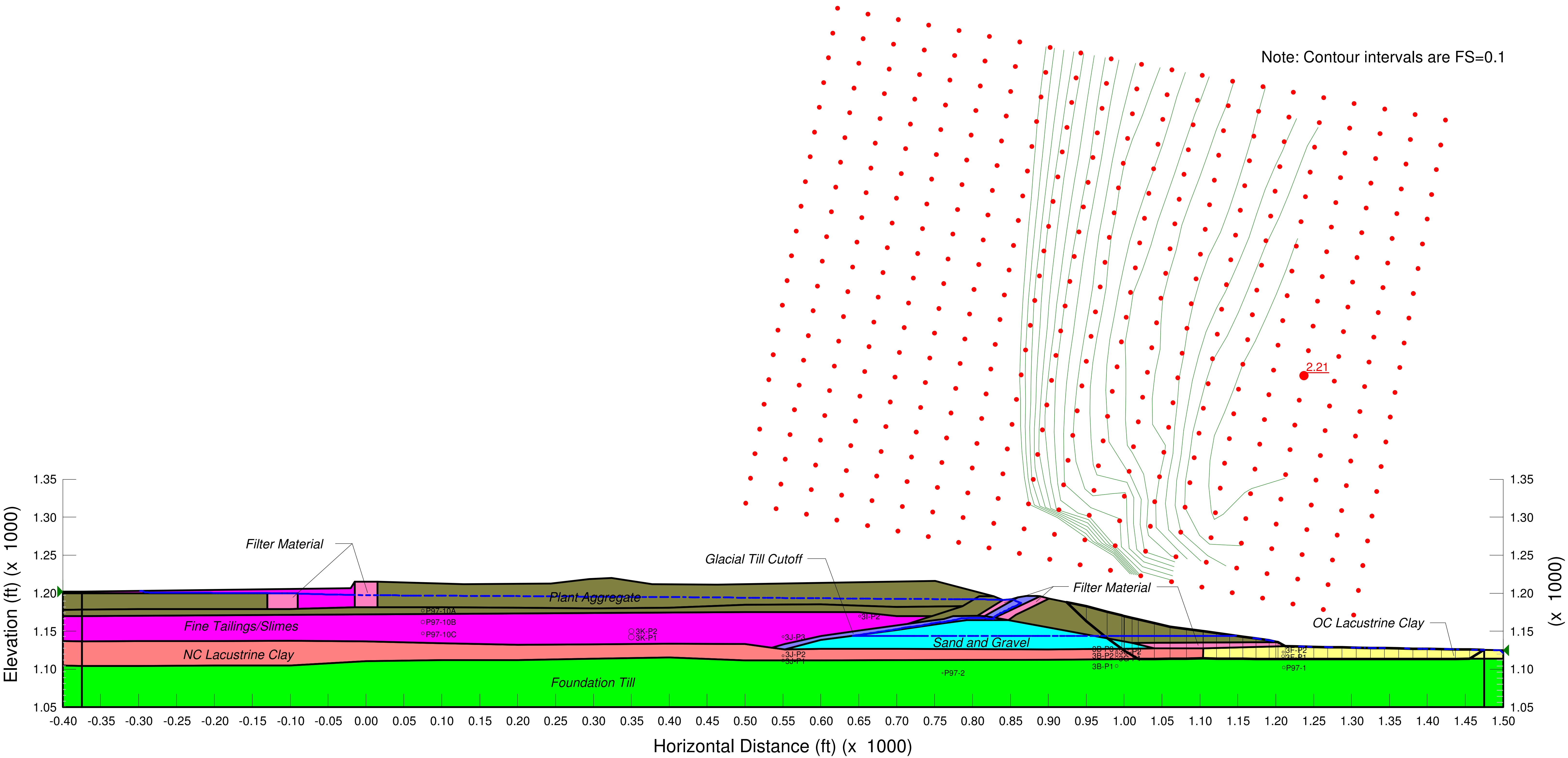
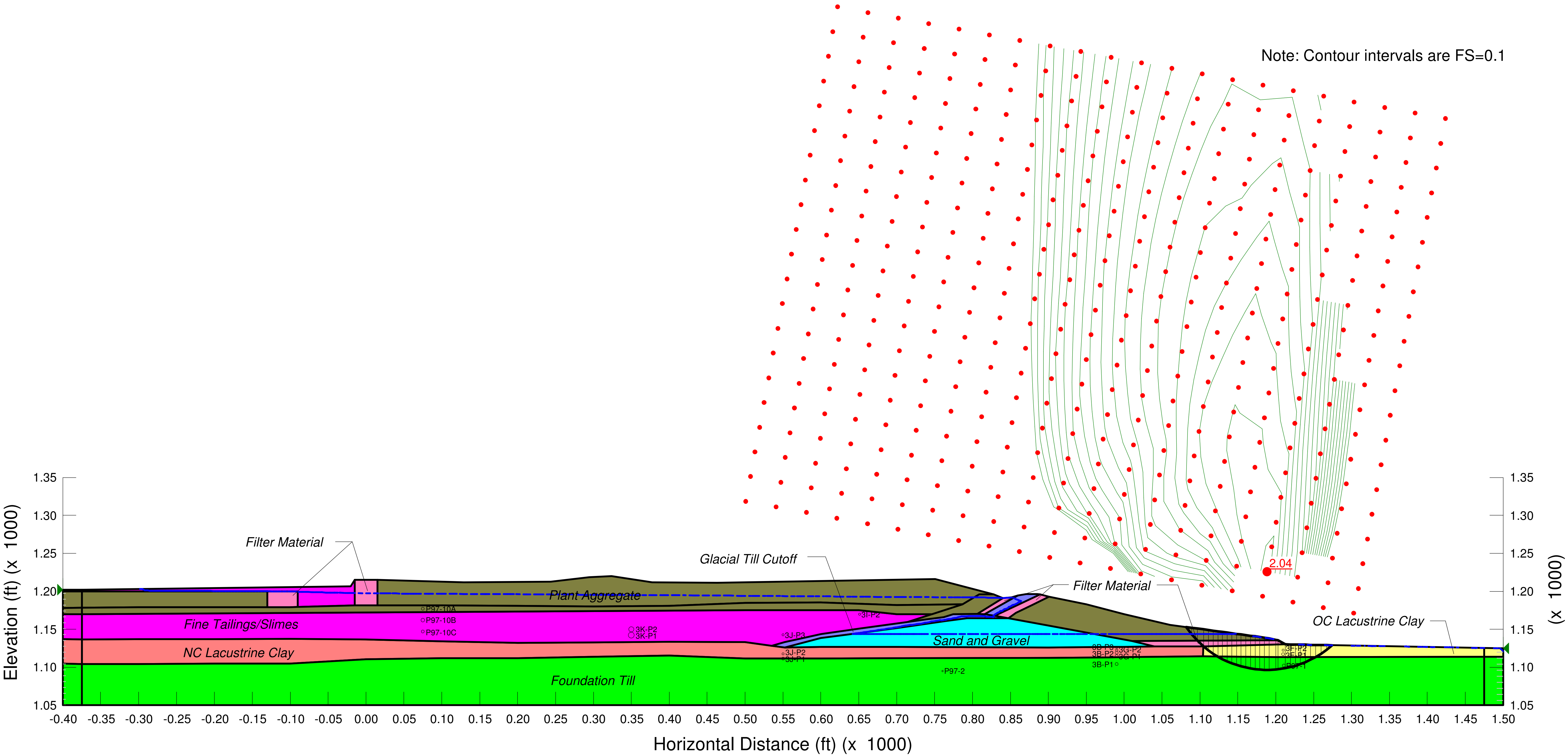
Last Saved Date: 11/17/2008
Factor of Safety: 2.21



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Low, FM Toe
File Name: D1_S2840_E1215_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.04



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Low, FM Block
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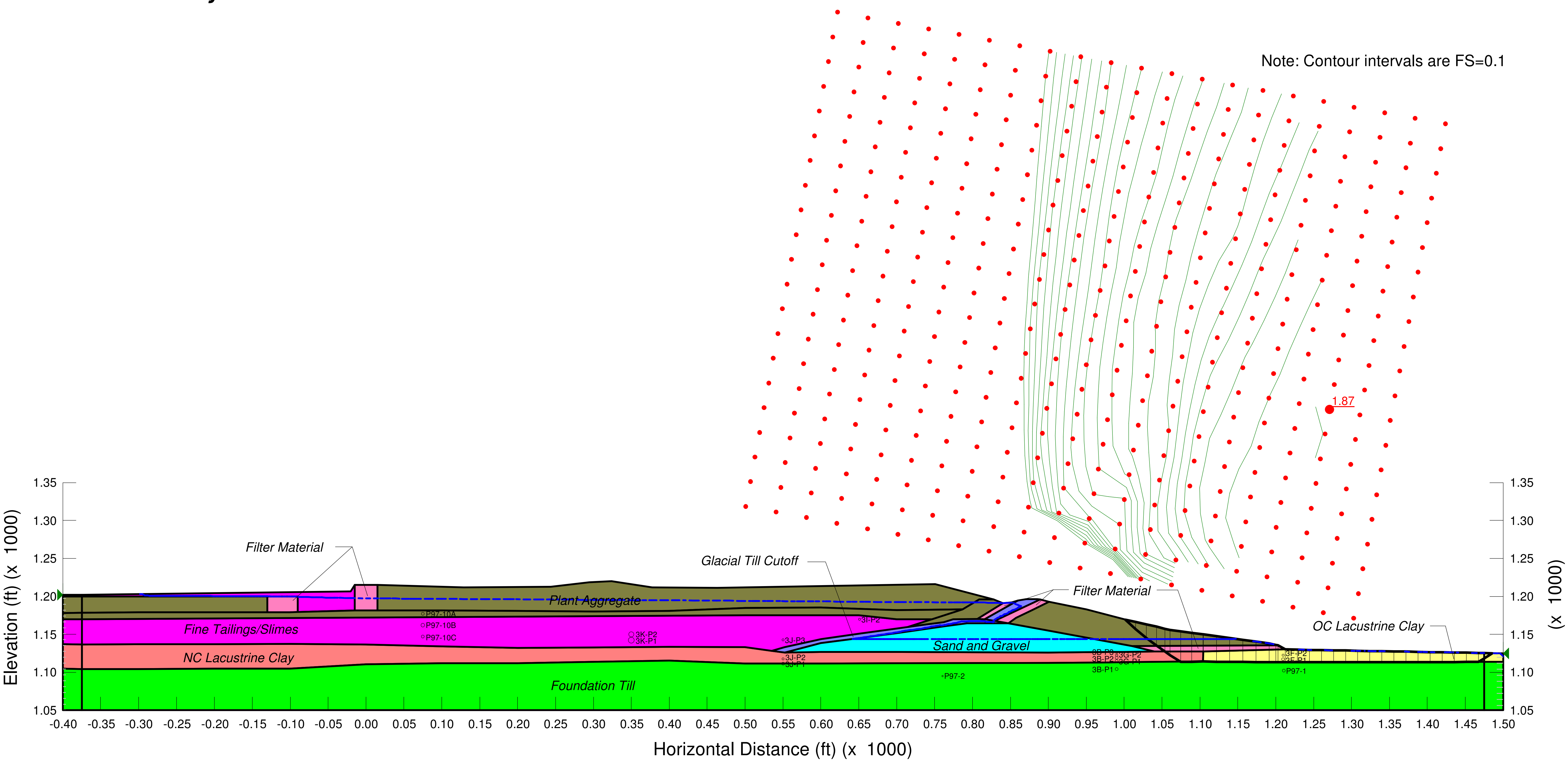
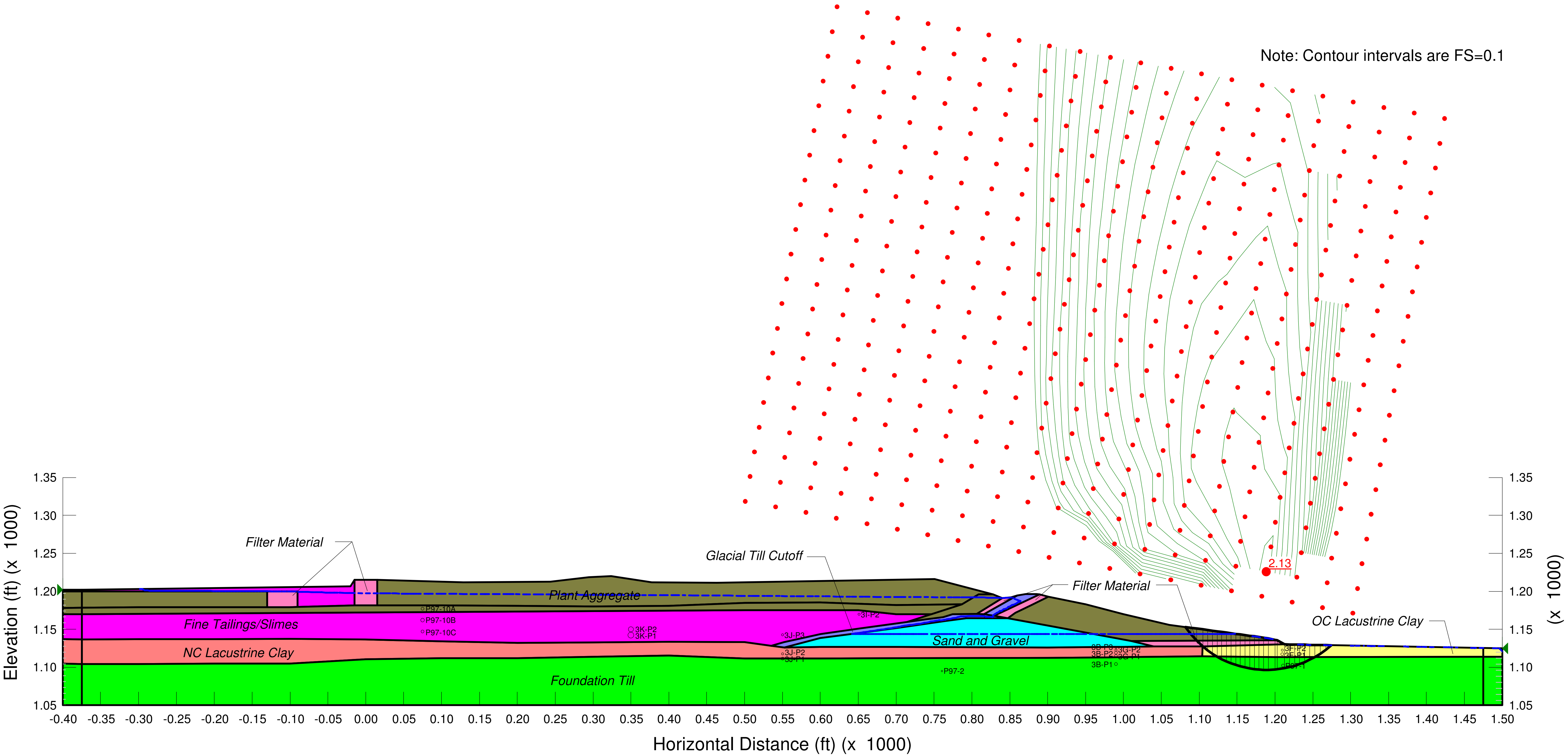
Last Saved Date: 11/17/2008
Factor of Safety: 1.87



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Average, FM Toe
File Name: D1_S2840_E1215_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.13



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Average, FM Block
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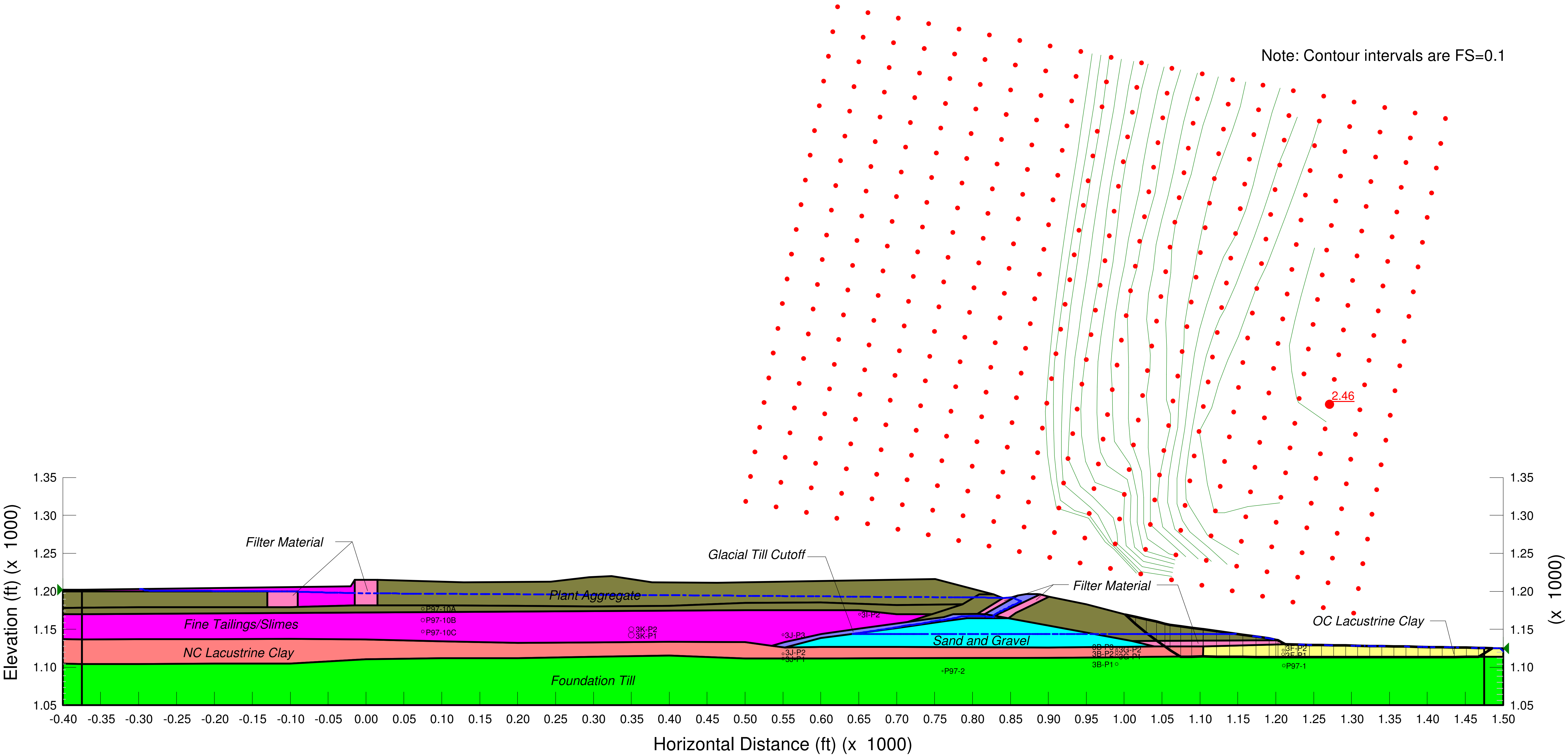
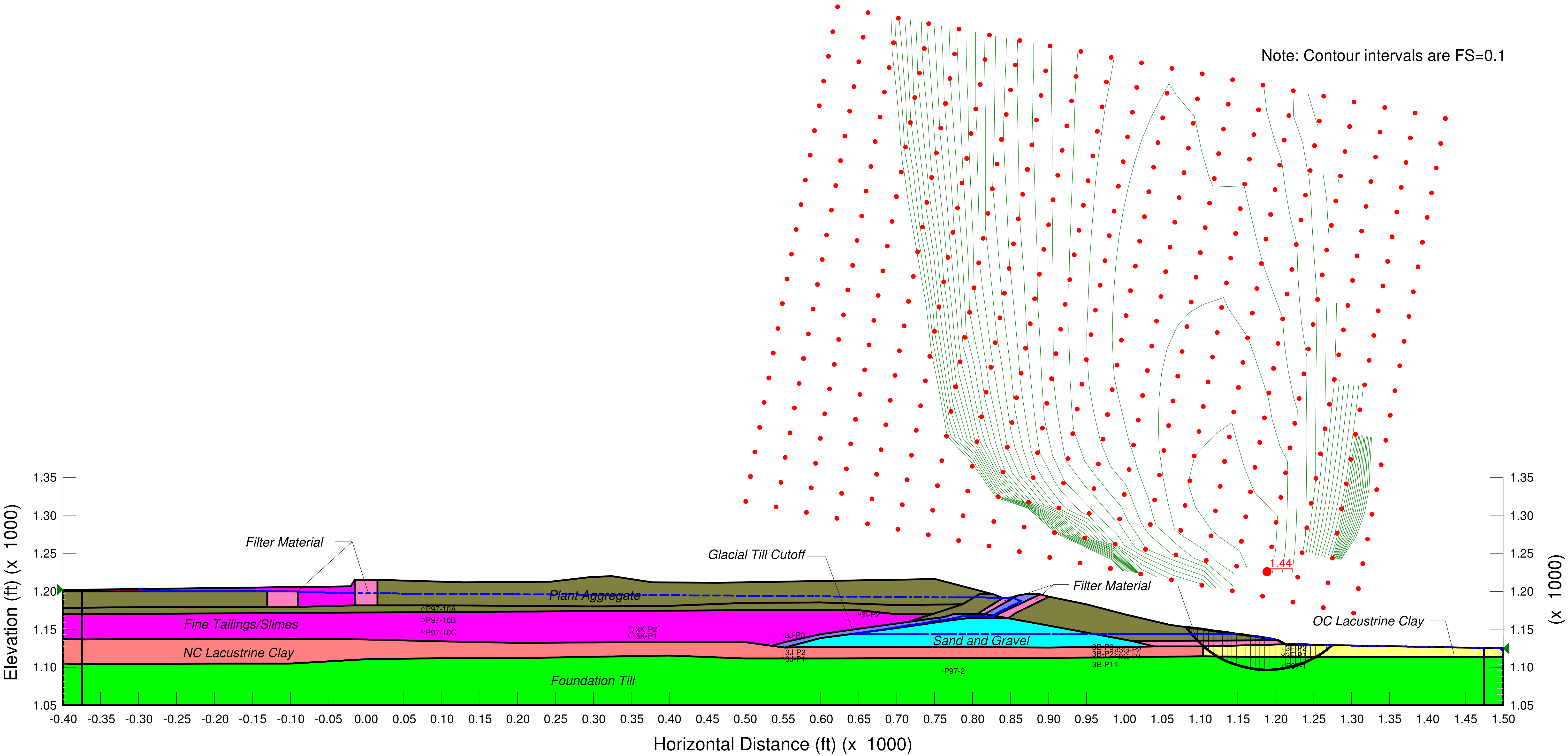
Last Saved Date: 11/17/2008
Factor of Safety: 2.46



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D1_S2840_E1215_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.1, FM Block
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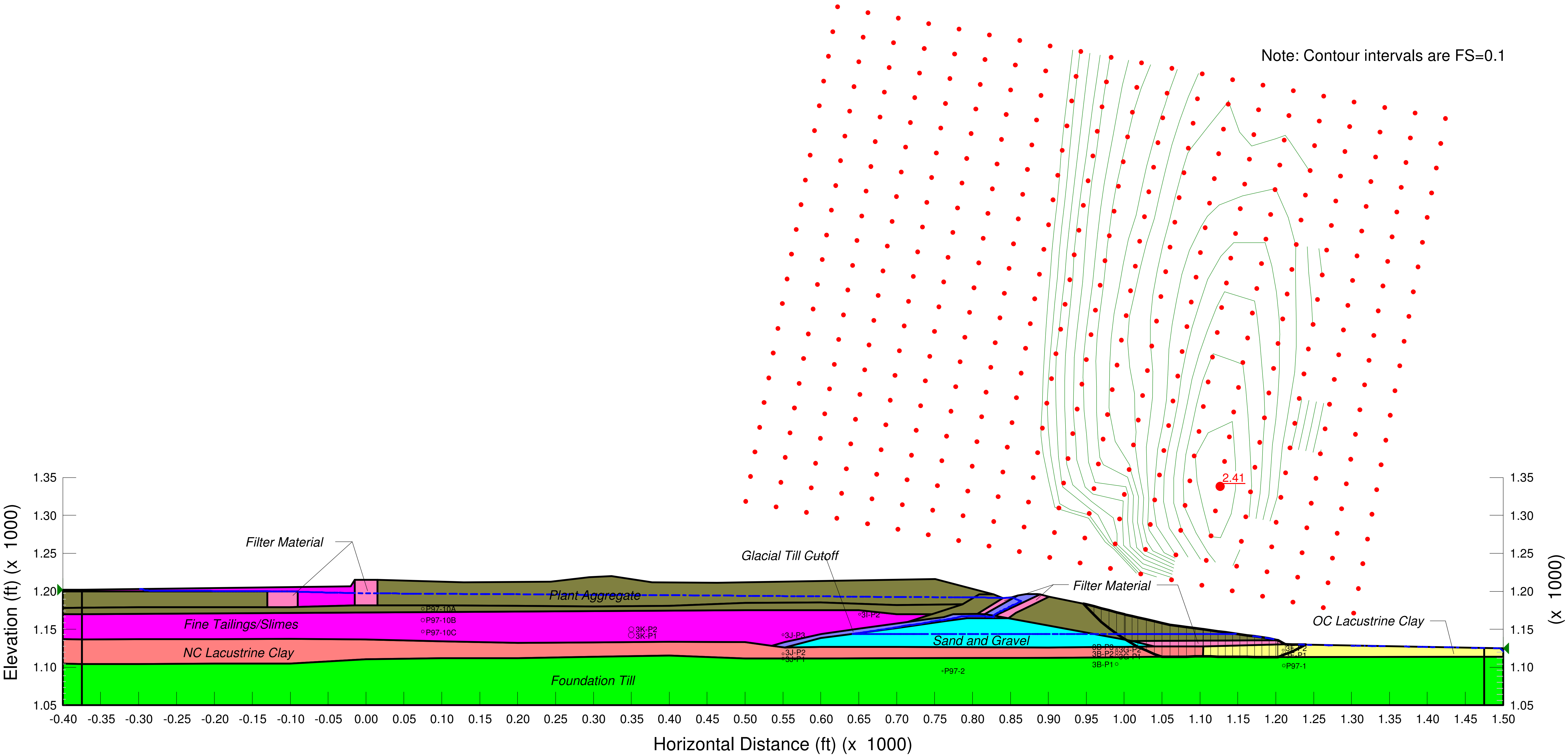
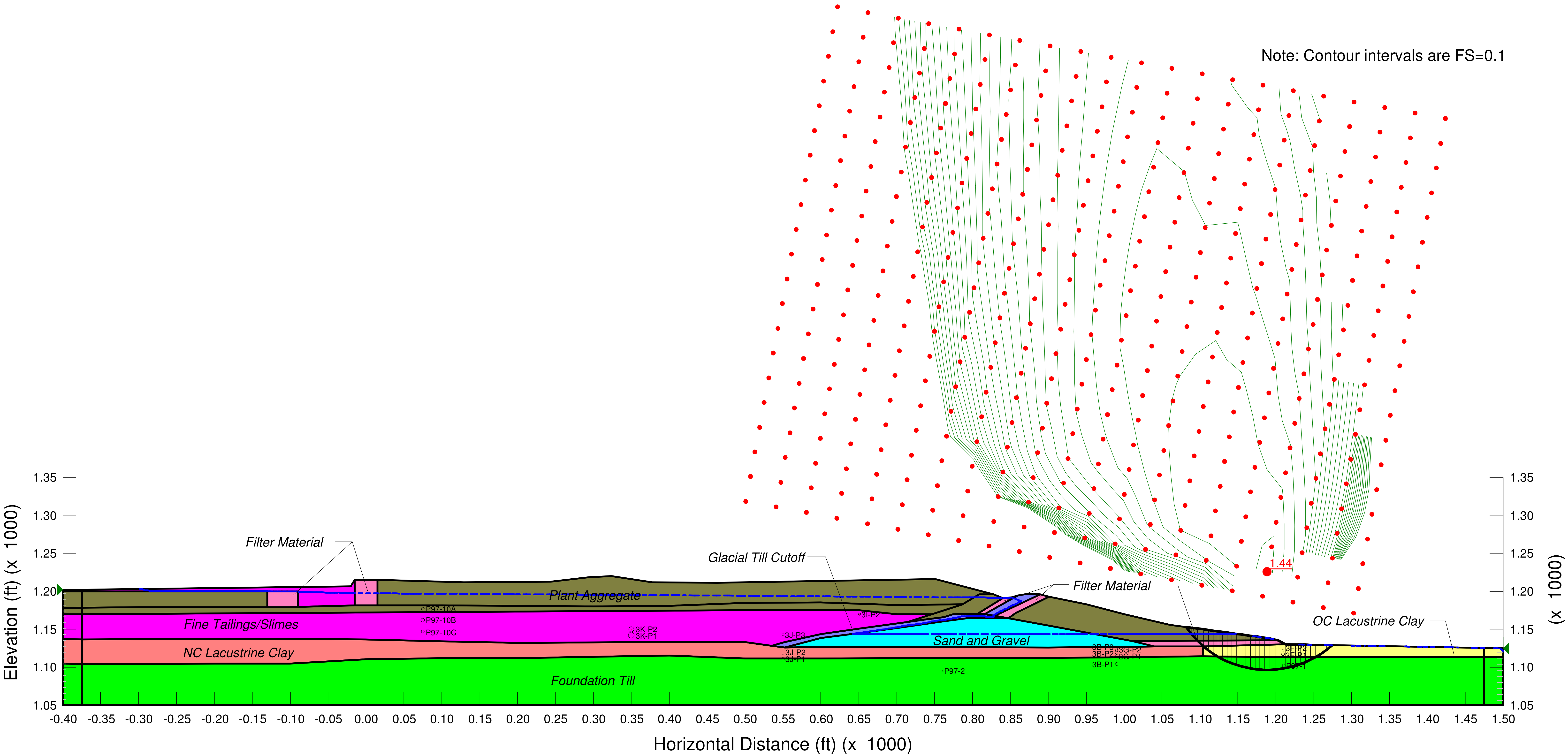
Last Saved Date: 11/17/2008
Factor of Safety: 2.41



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D1_S2840_E1215_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.1, FM Block
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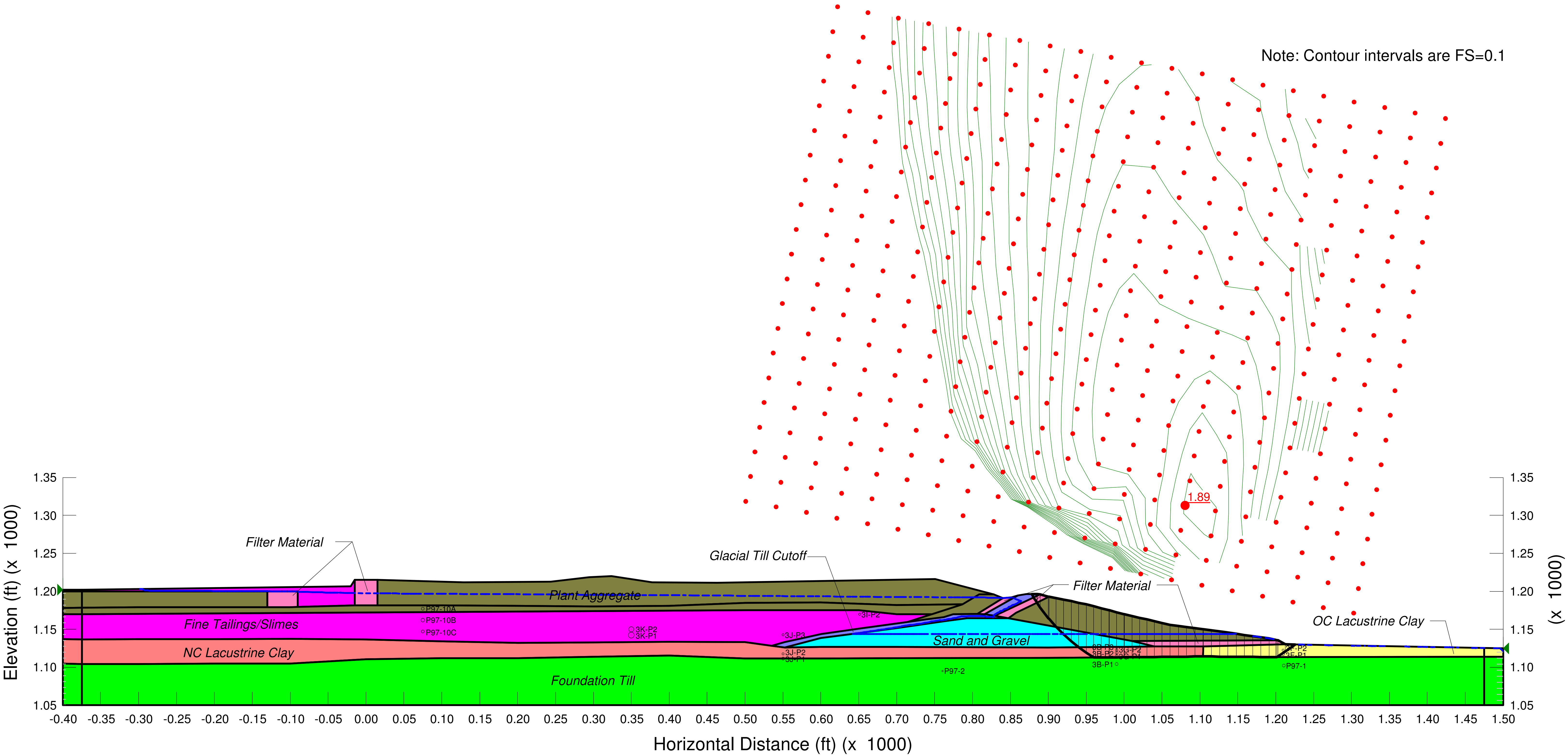
Last Saved Date: 11/17/2008
Factor of Safety: 1.89



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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File Name: D1_S2840_E1215_USSA_LC7_FT1_FM1.gsz
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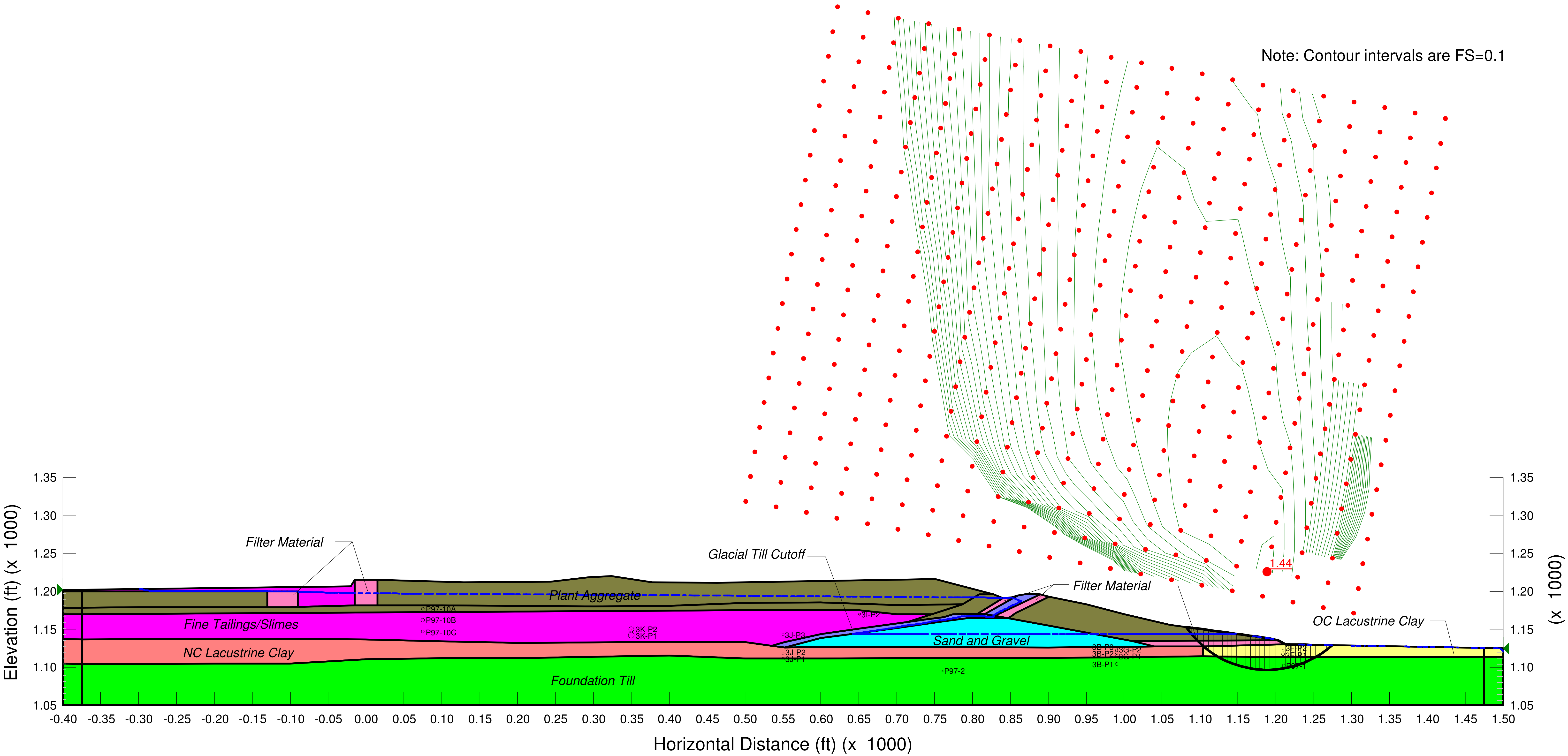
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.1, FM Block
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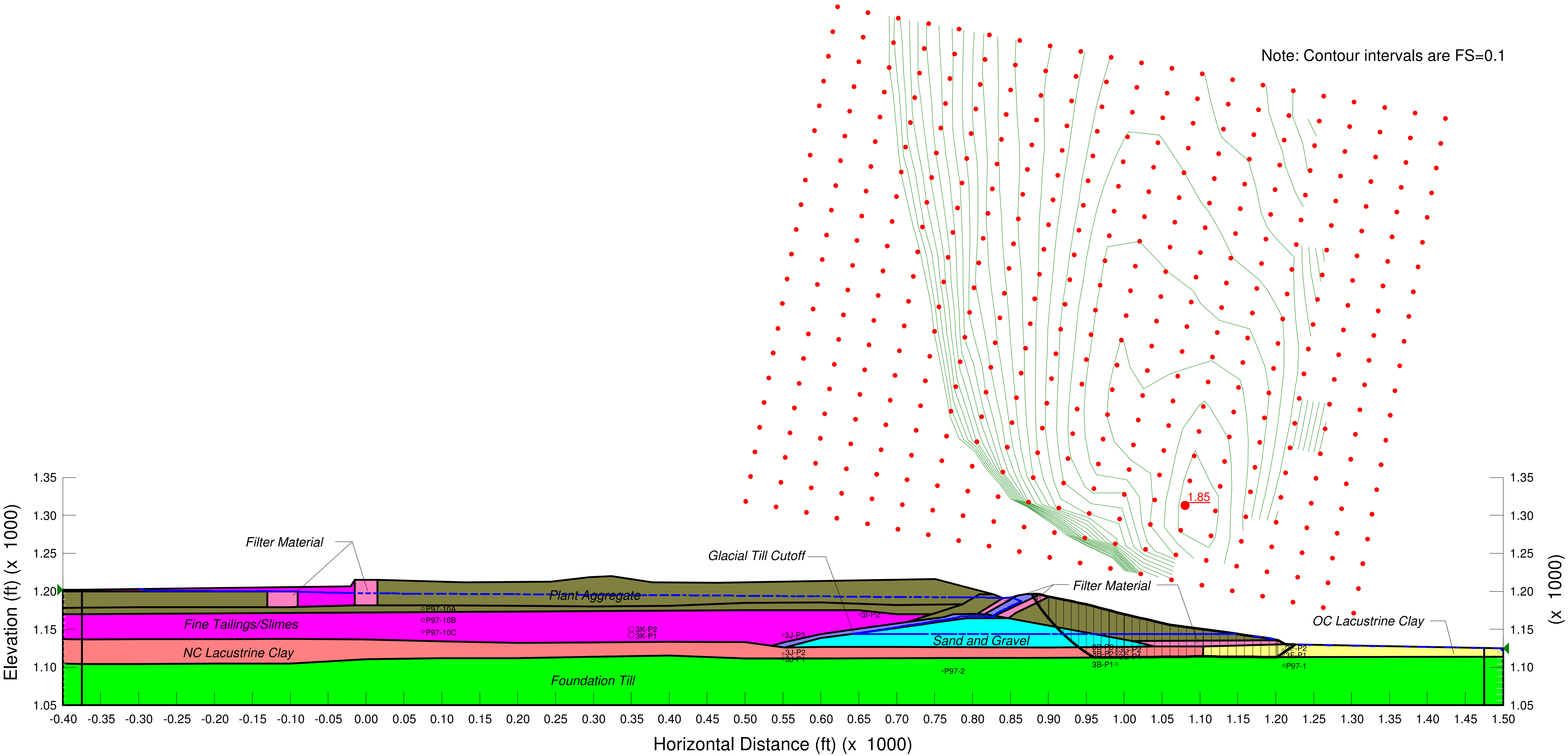
Factor of Safety: 1.85



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.1, FM Toe
_File Name: D1_S2840_E1215_USSA_LC8_FT1_FM1.gsz_
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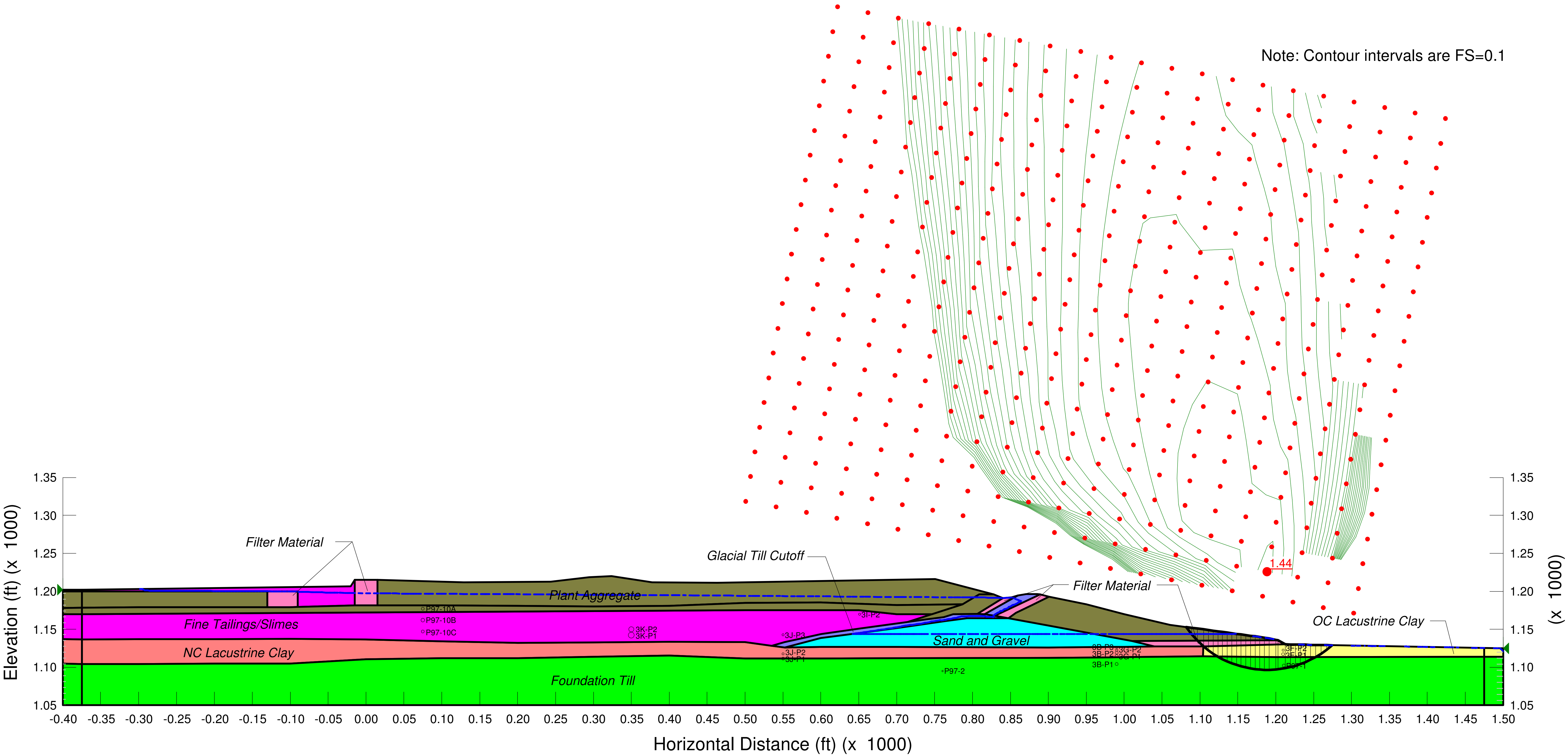
Factor of Safety: 1.44



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.1, FM Block
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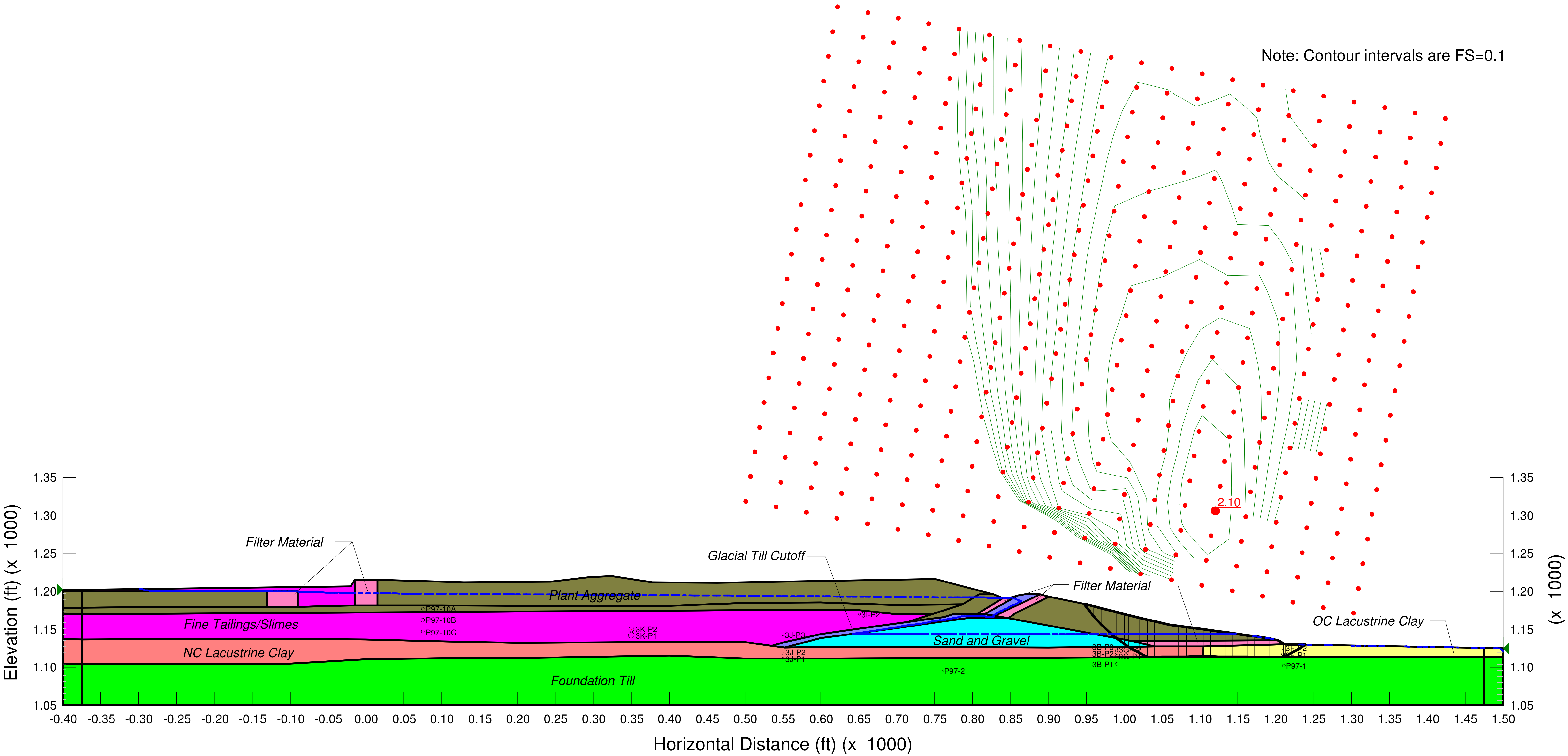
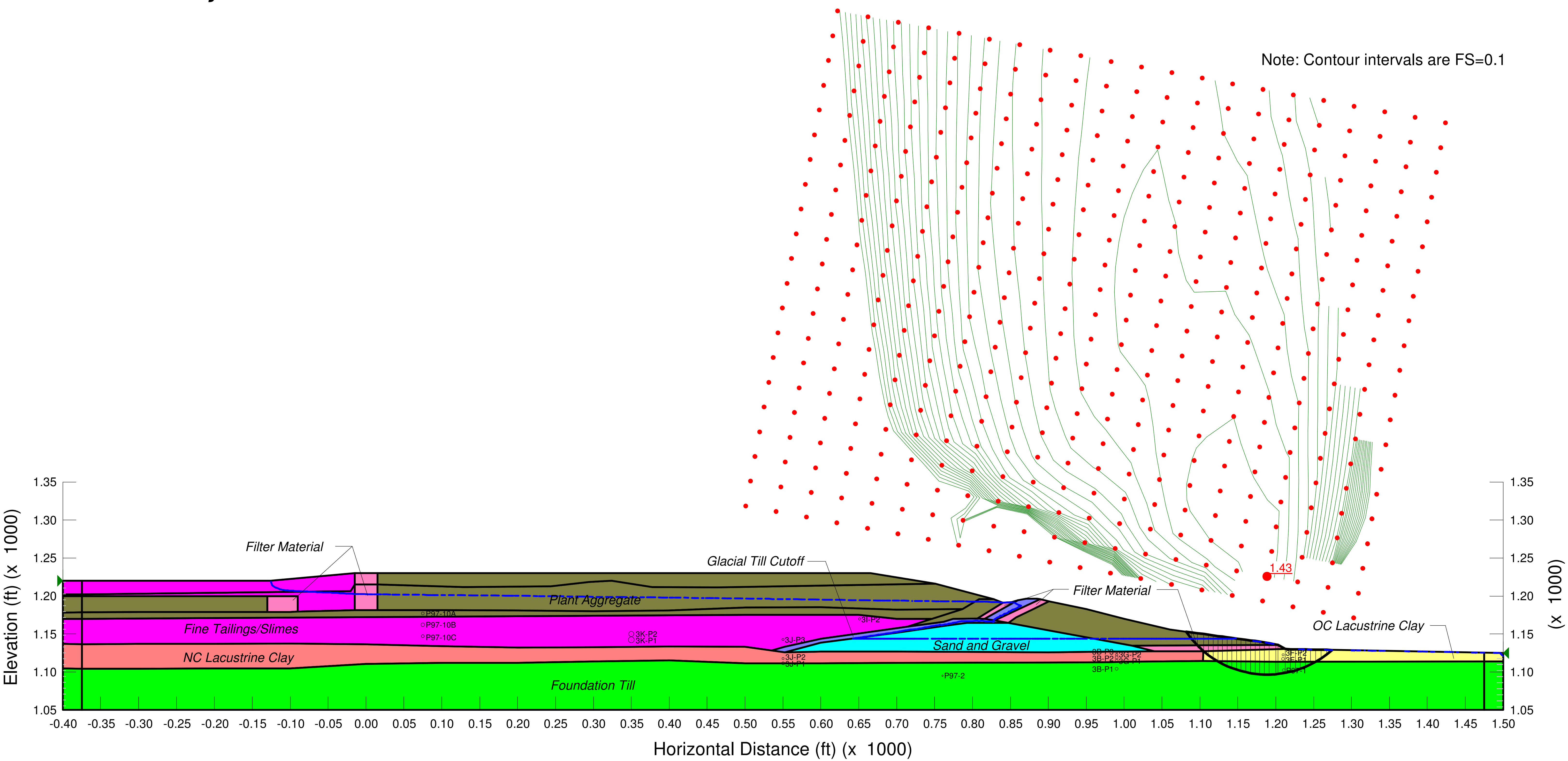
Last Saved Date: 11/17/2008
Factor of Safety: 2.10



Proposed Geometry El. 1,230 feet

Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D1_S2840_E1230_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.2, FM Block
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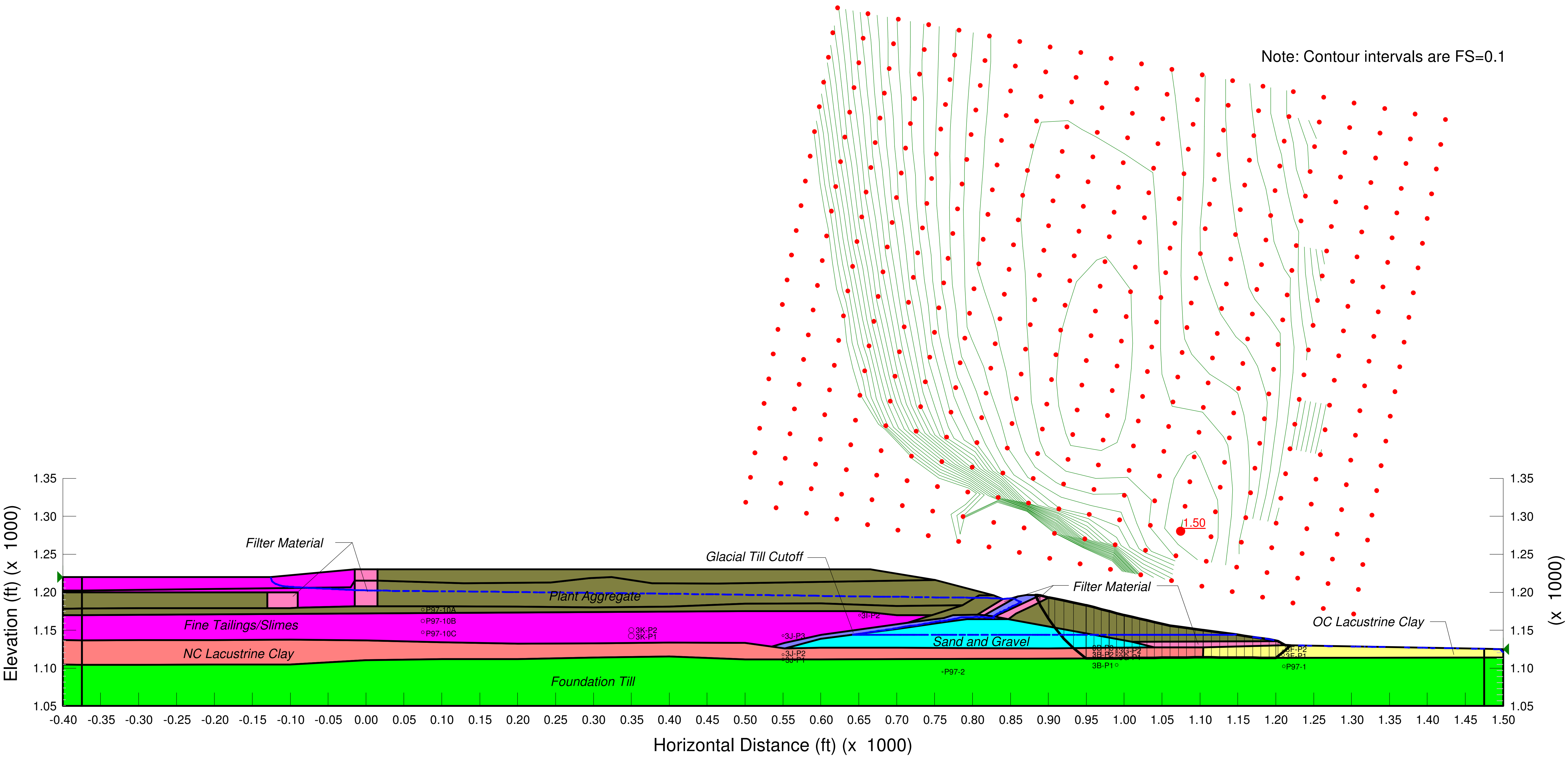
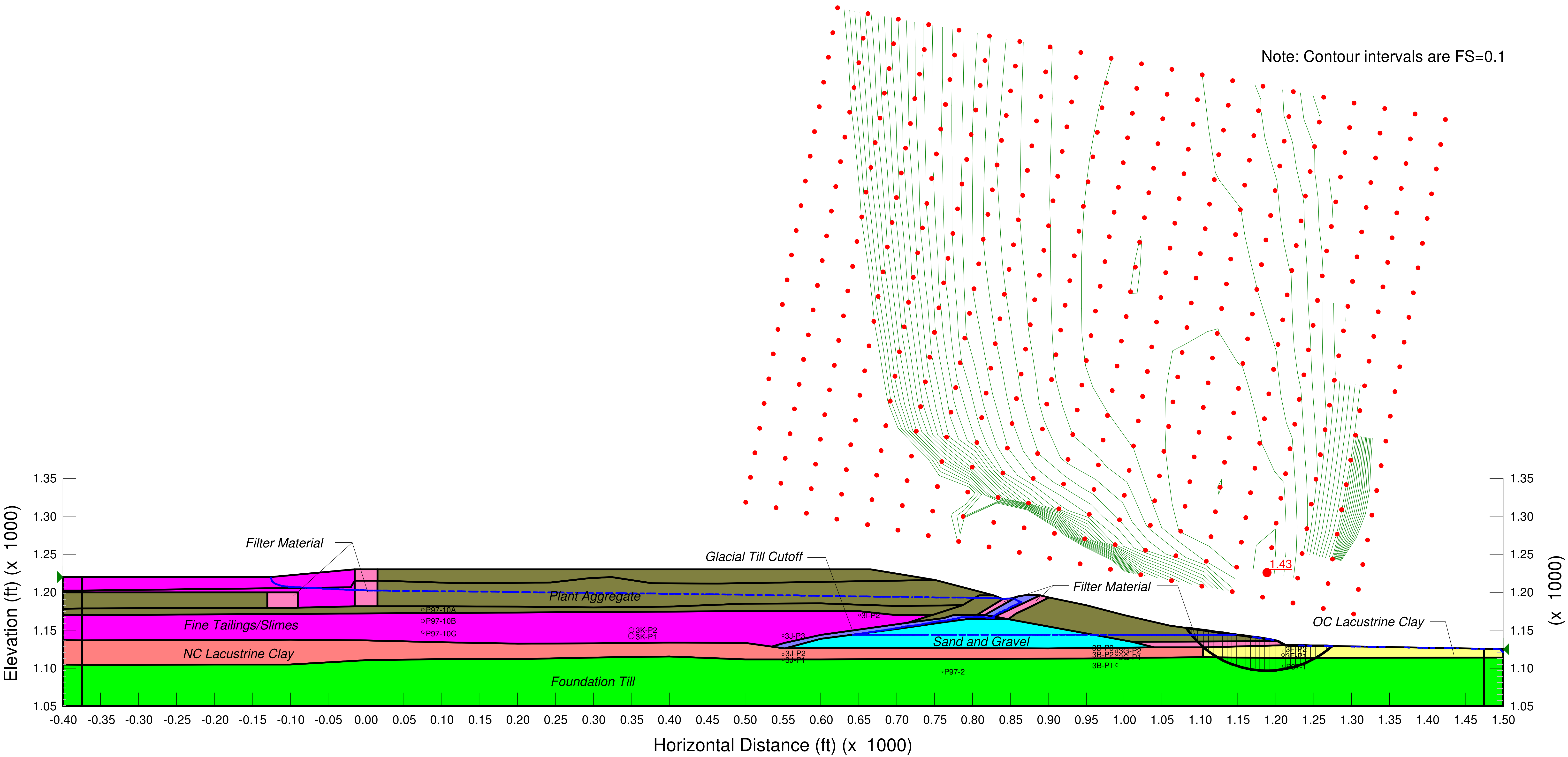
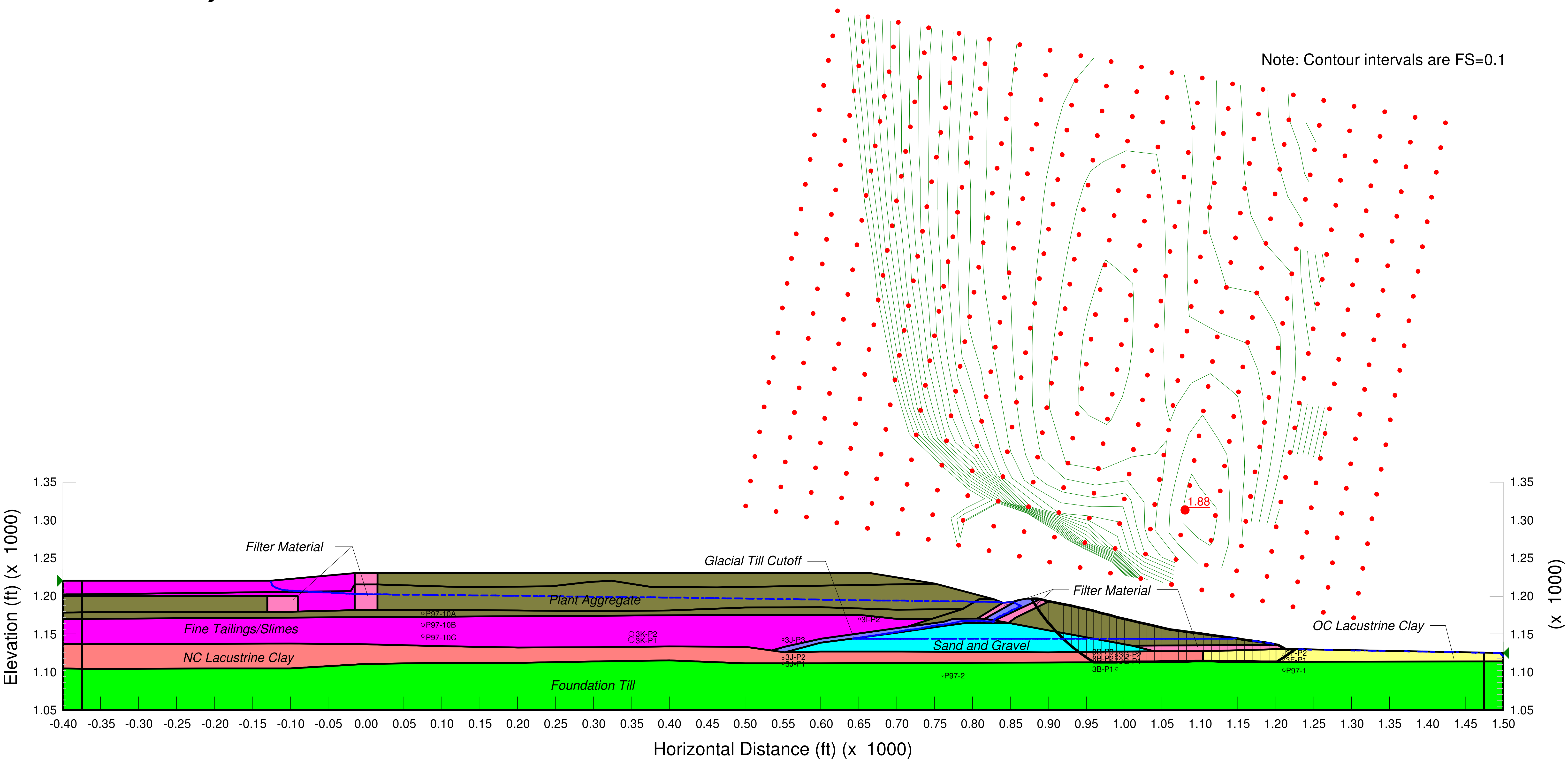
Last Saved Date: 6/19/2009
Factor of Safety: 1.50



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D1_S2840_E1230_USSA_LC6_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.2, FM Block
File Name: D1_S2840_E1230_USSA_LC6_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.88



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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File Name: D1_S2840_E1230_USSA_LC7_FT2_FM1.gsz
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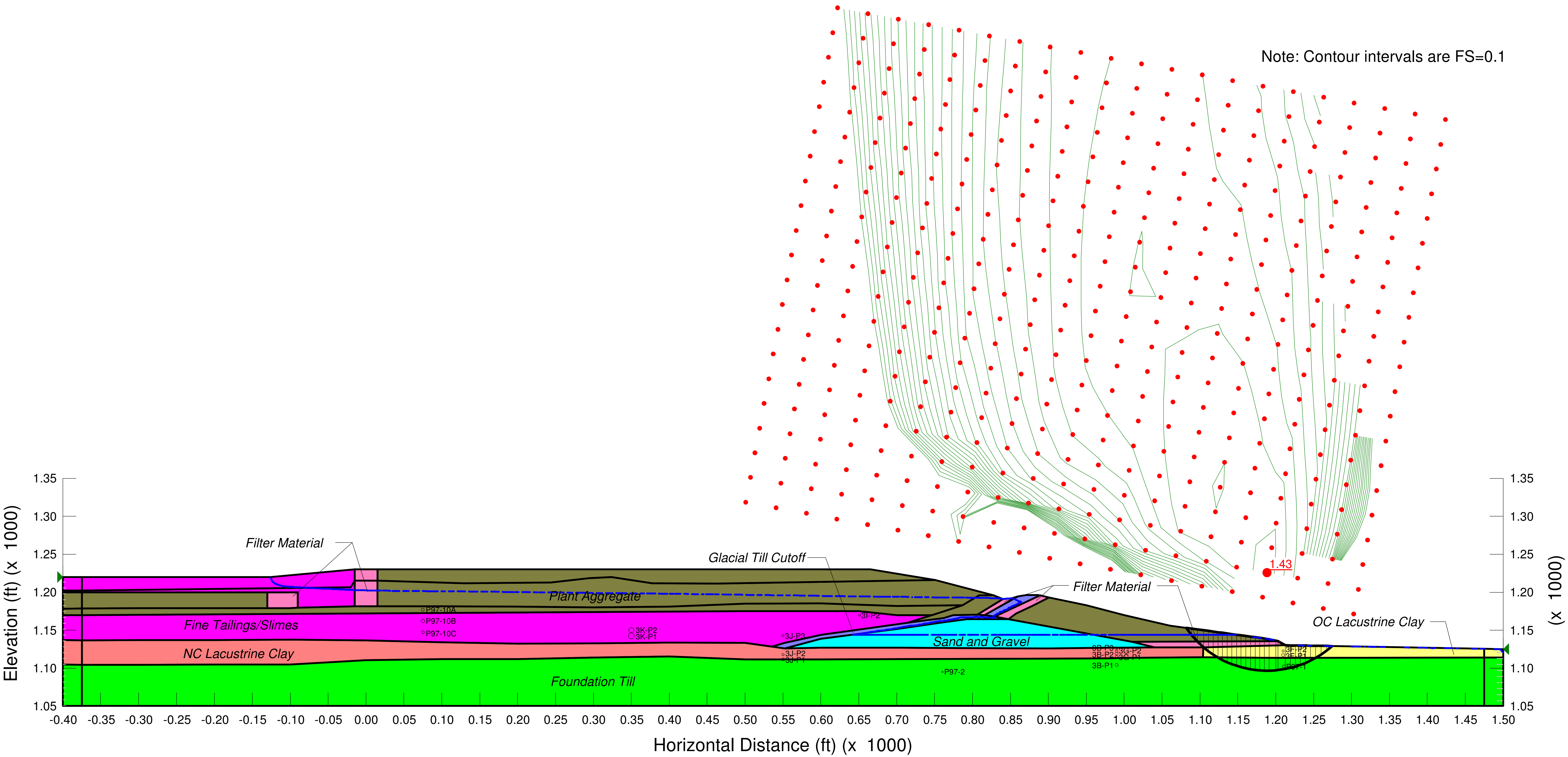
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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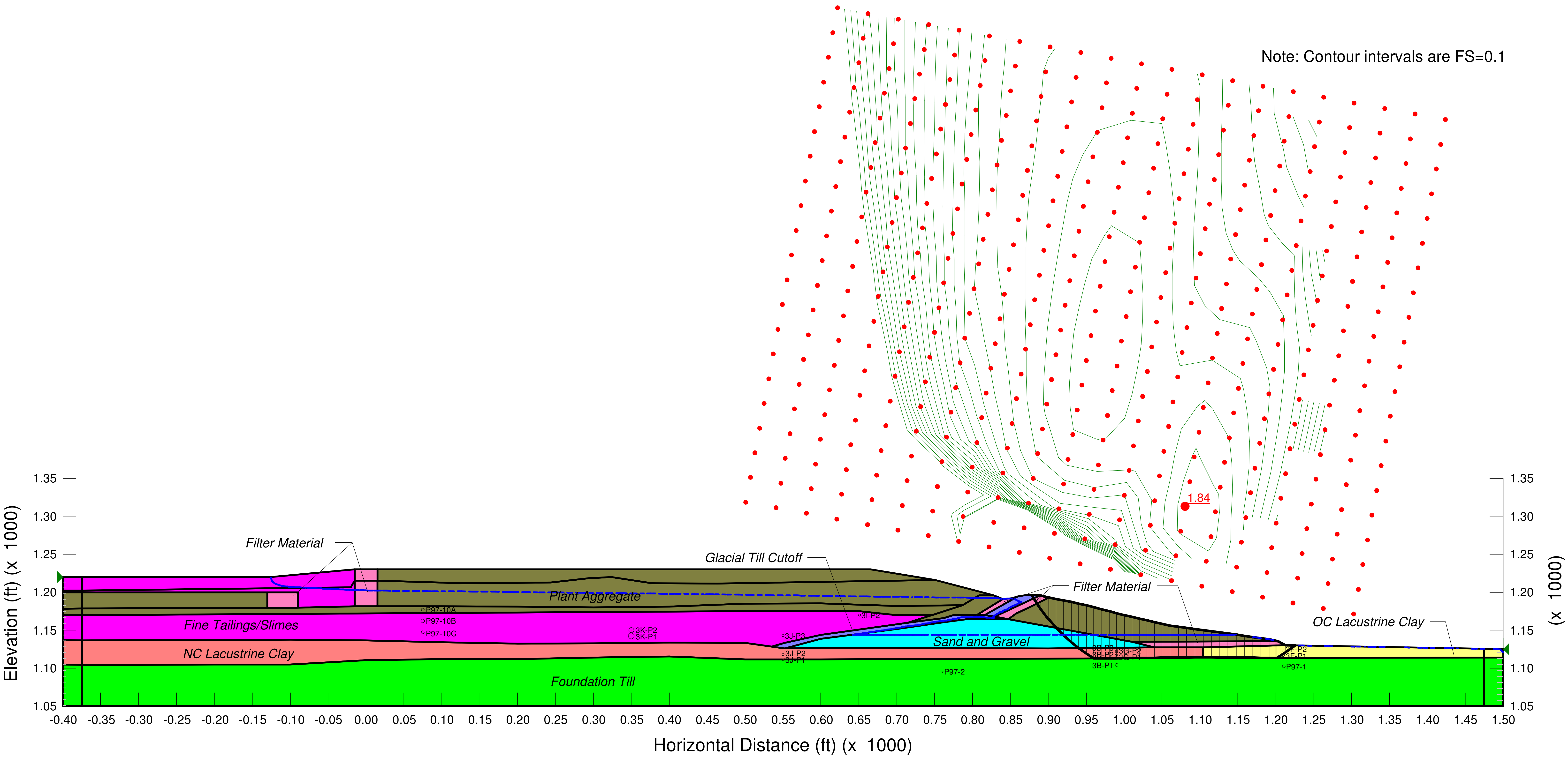
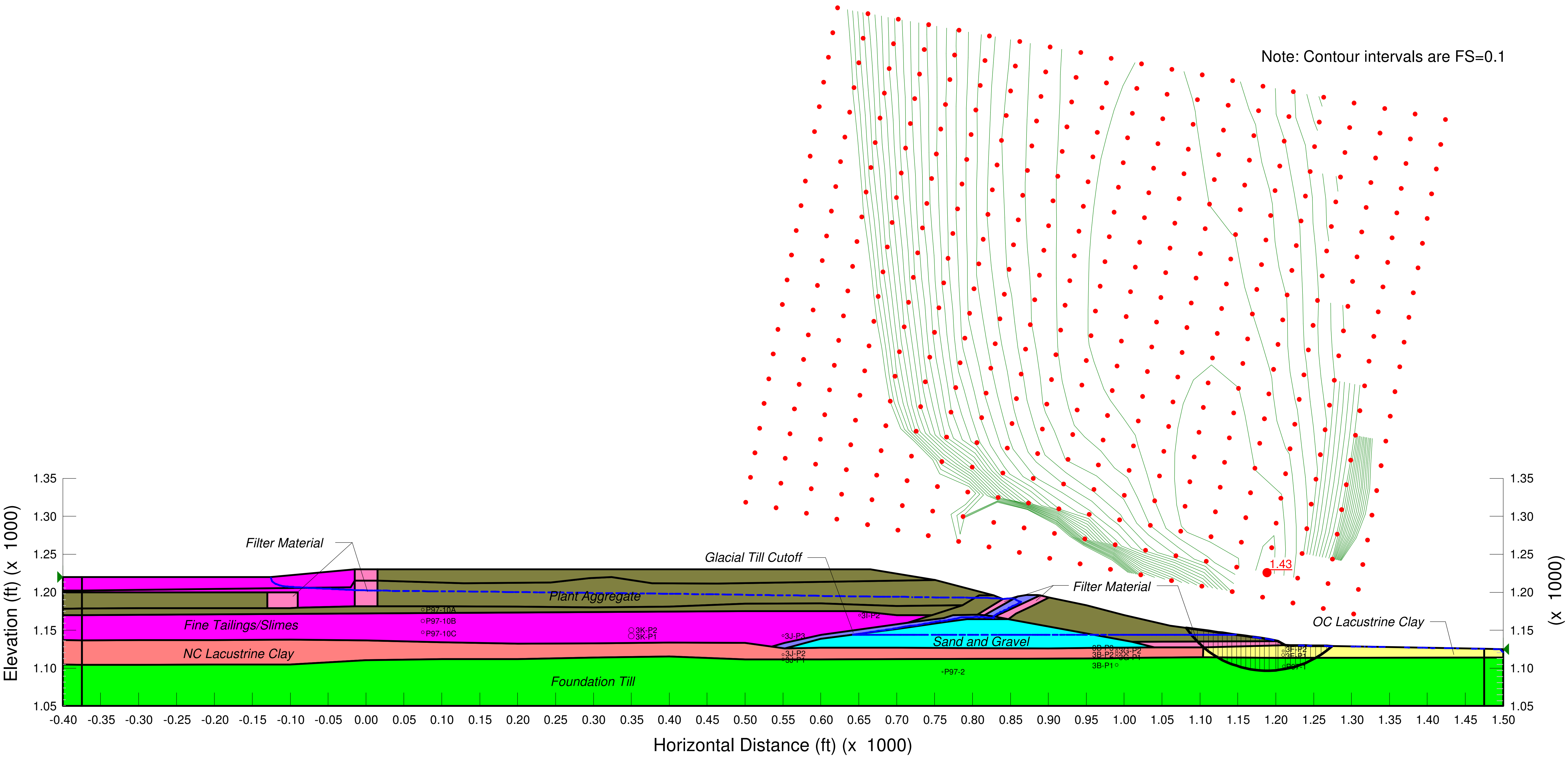
Last Saved Date: 6/19/2009
Factor of Safety: 1.84



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D1_S2840_E1230_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.2, FM Block
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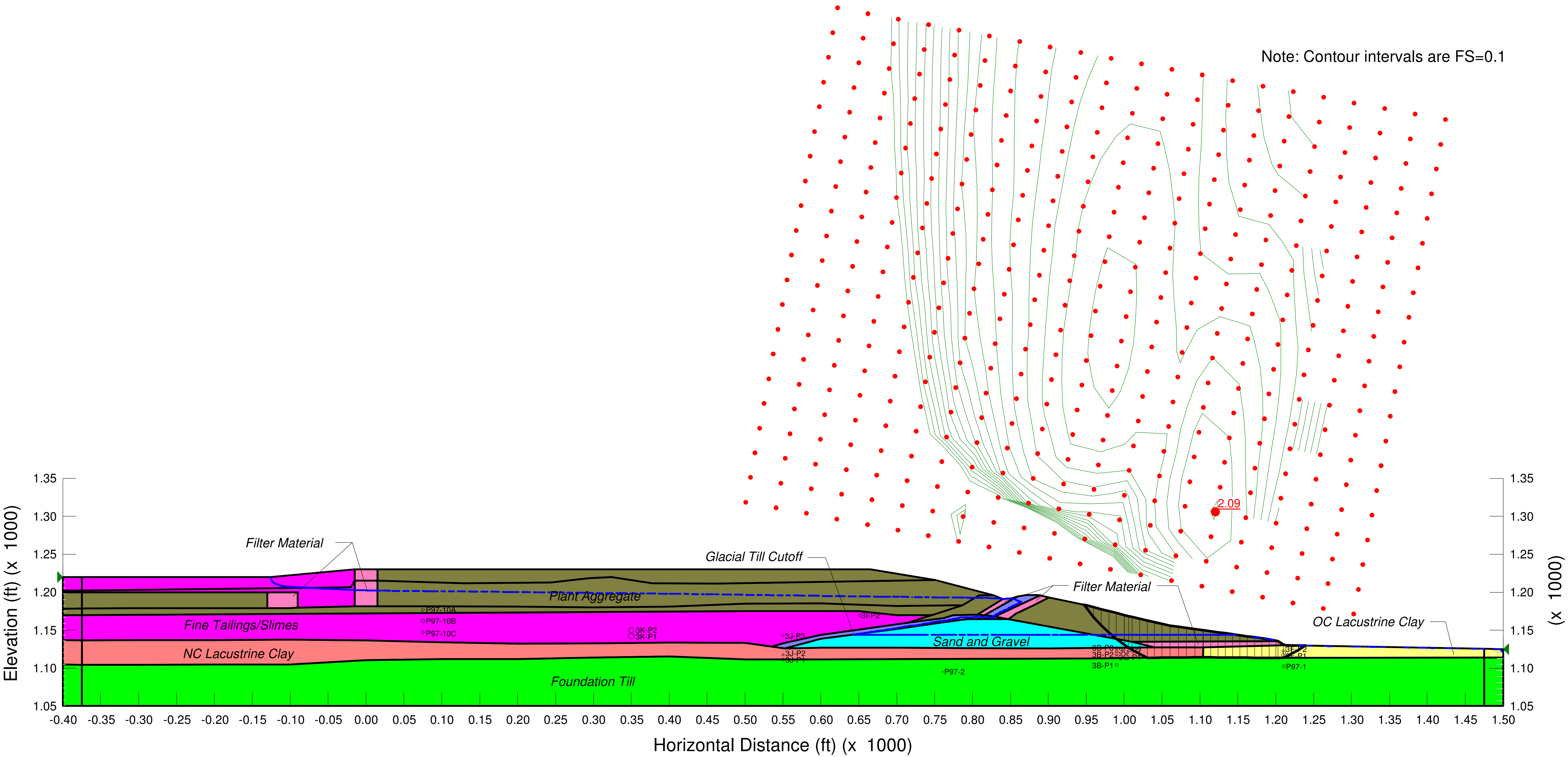
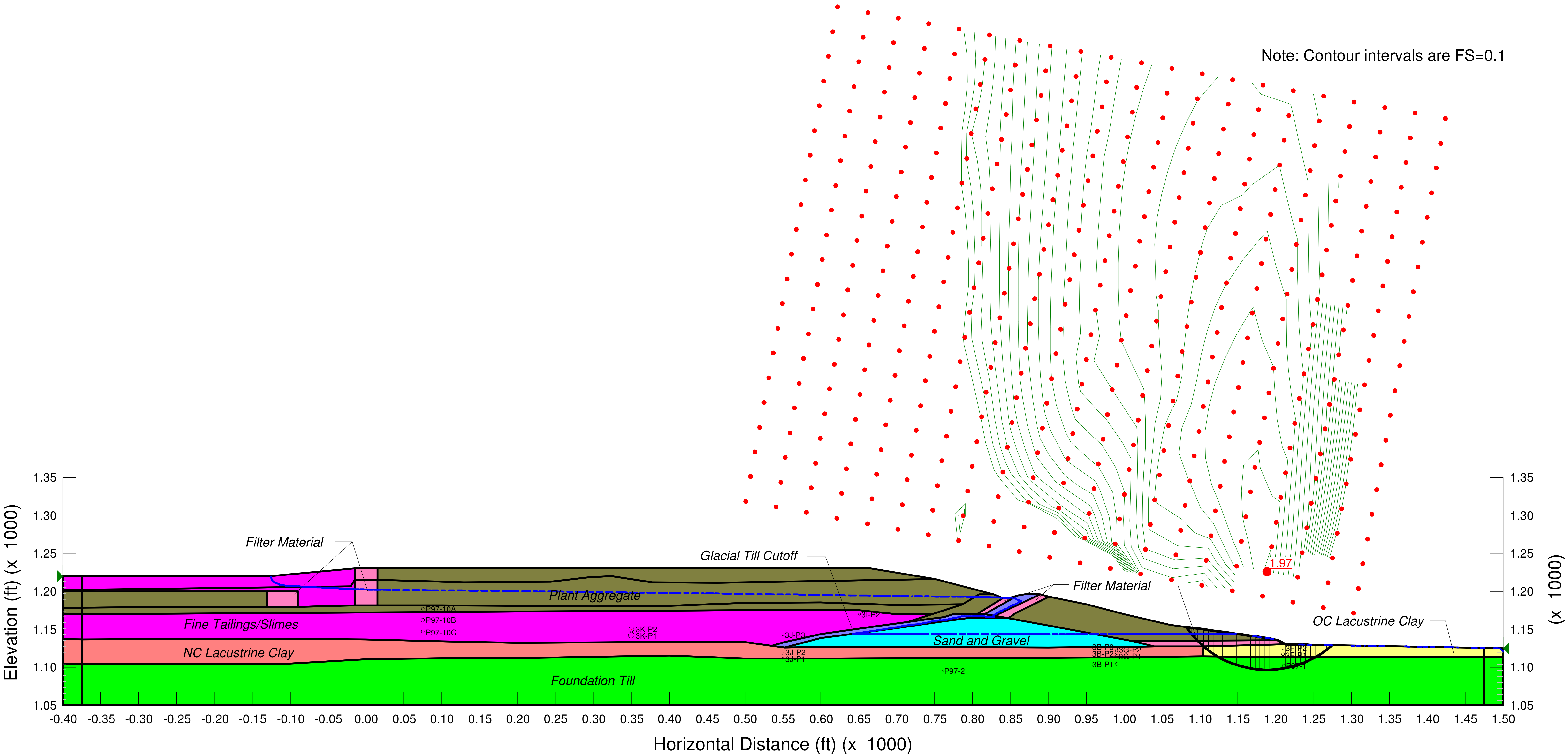
Last Saved Date: 6/19/2009
Factor of Safety: 2.09



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Toe
File Name: D1_S2840_E1230_ESSA_LC1_FM1.gsz
Last Saved Date: 11/14/2008
Factor of Safety: 1.97



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Block
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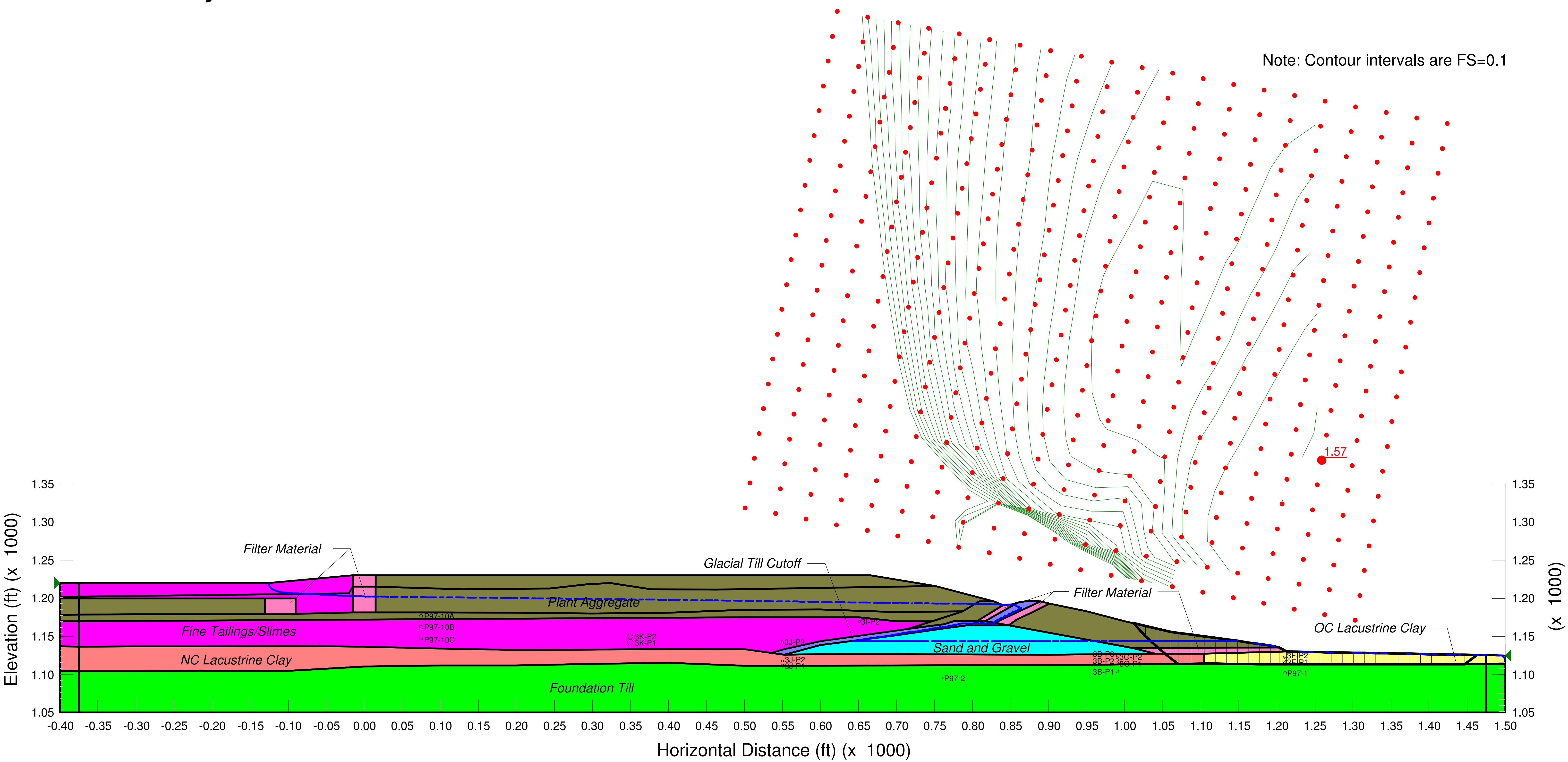
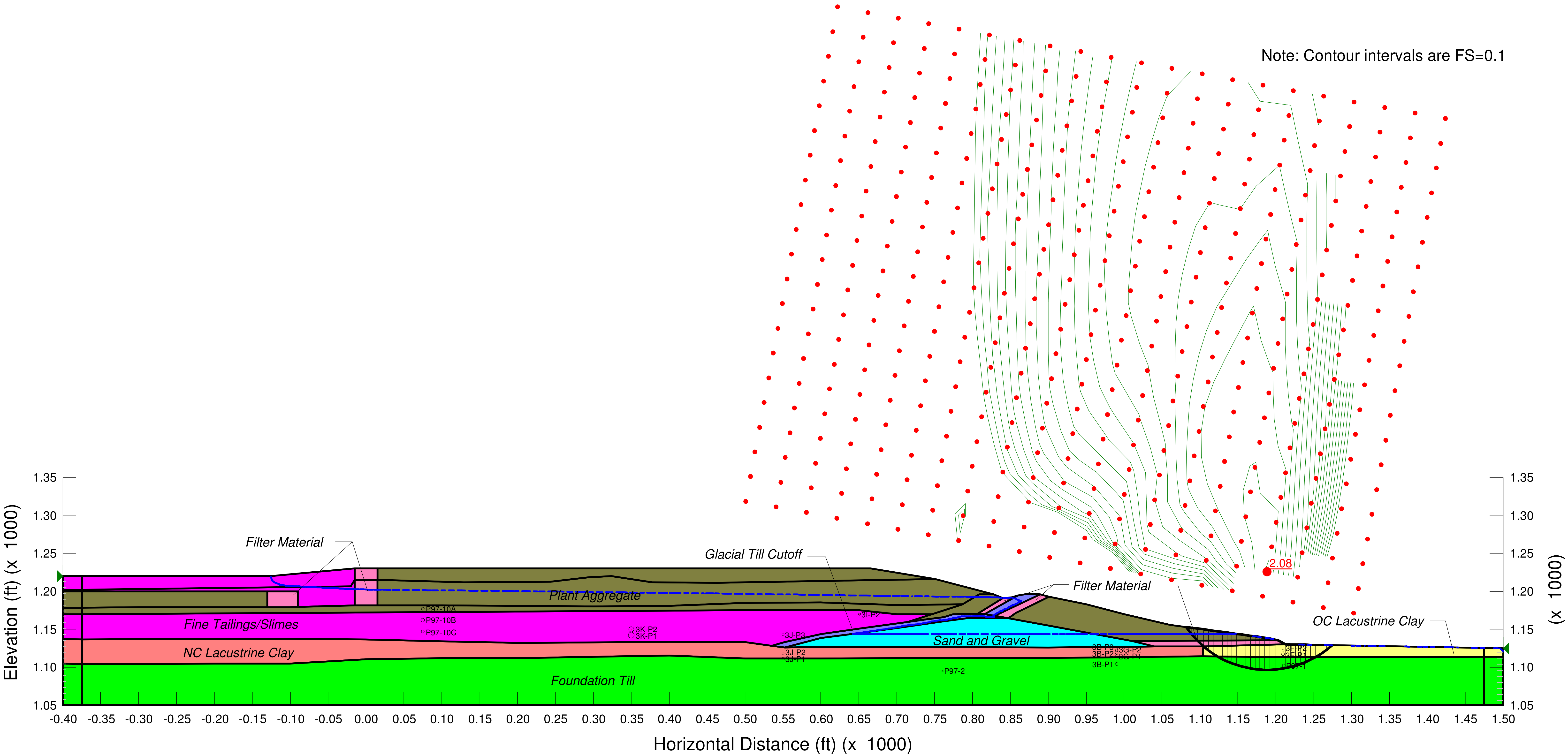
Last Saved Date: 11/17/2008
Factor of Safety: 1.57



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Toe
File Name: D1_S2840_E1230_ESSA_LC2_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.08



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Block
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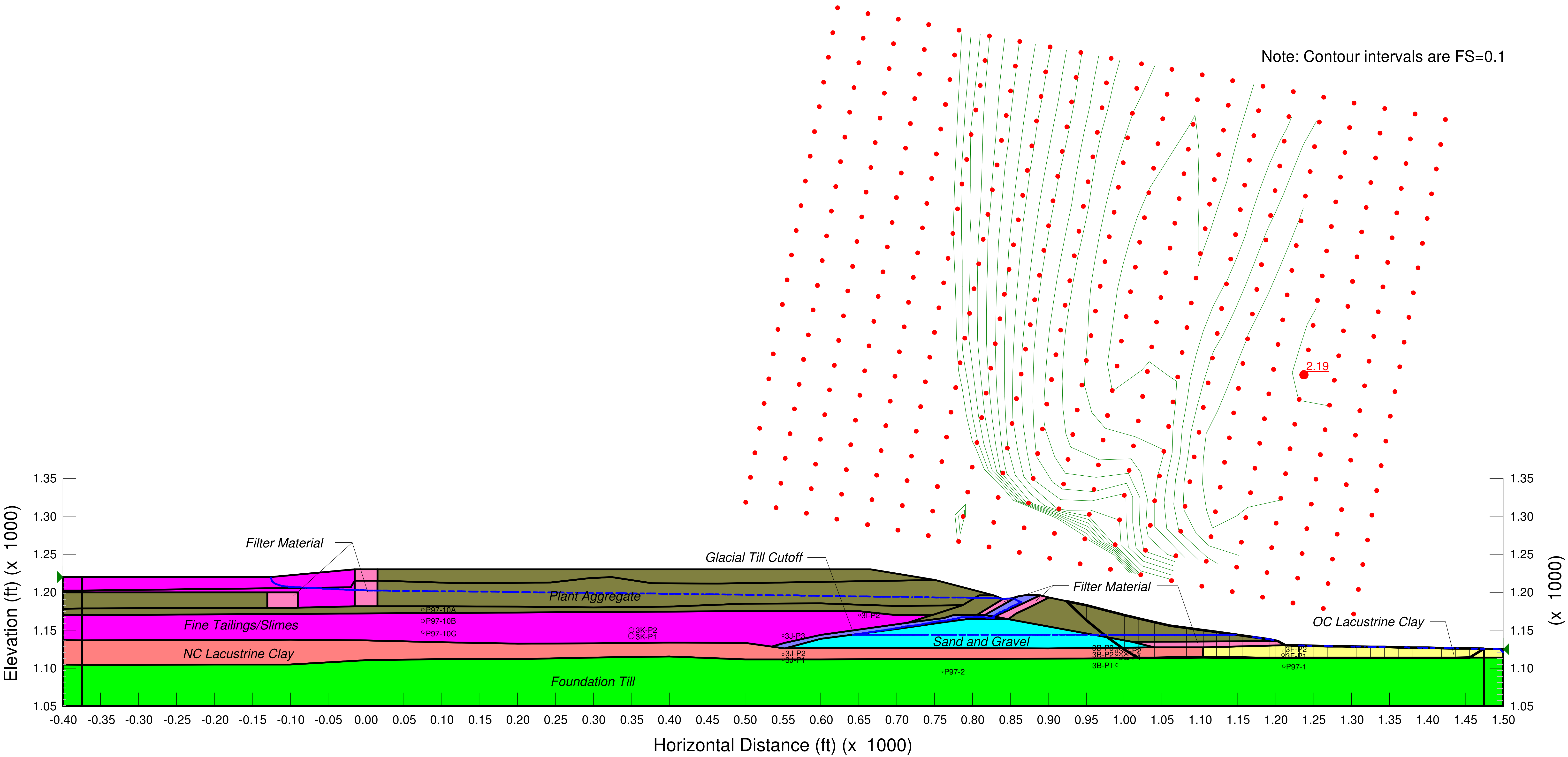
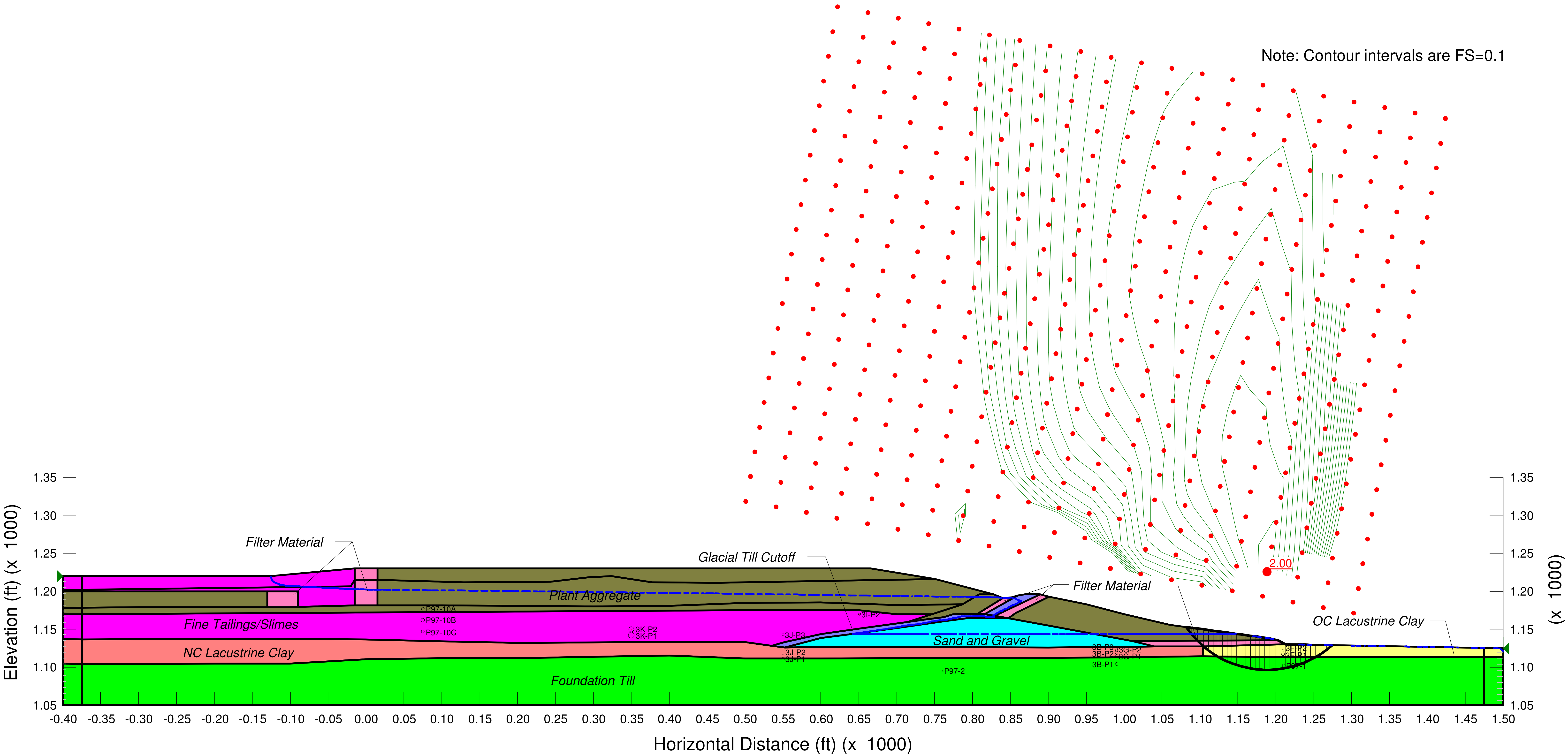
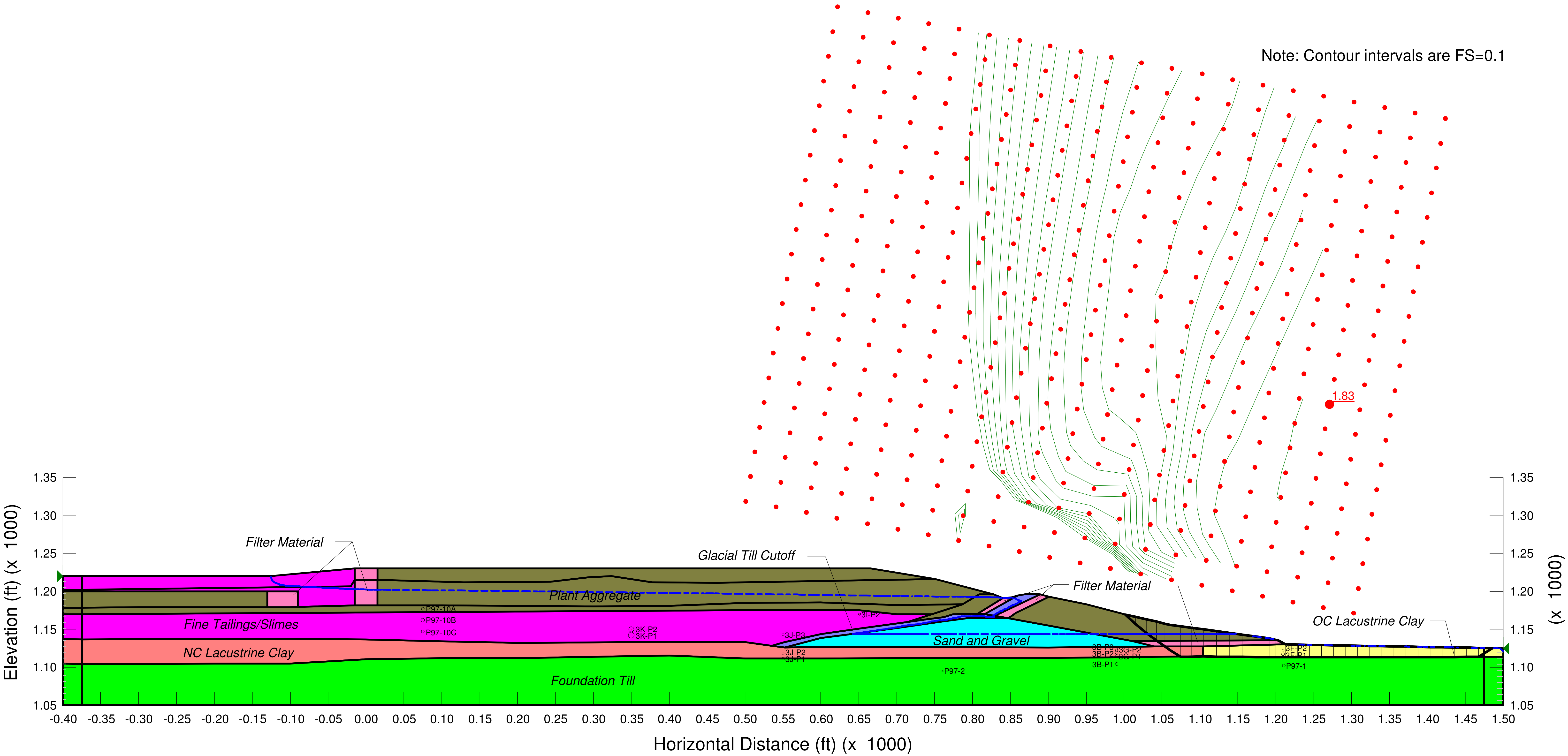
Last Saved Date: 11/17/2008
Factor of Safety: 2.19



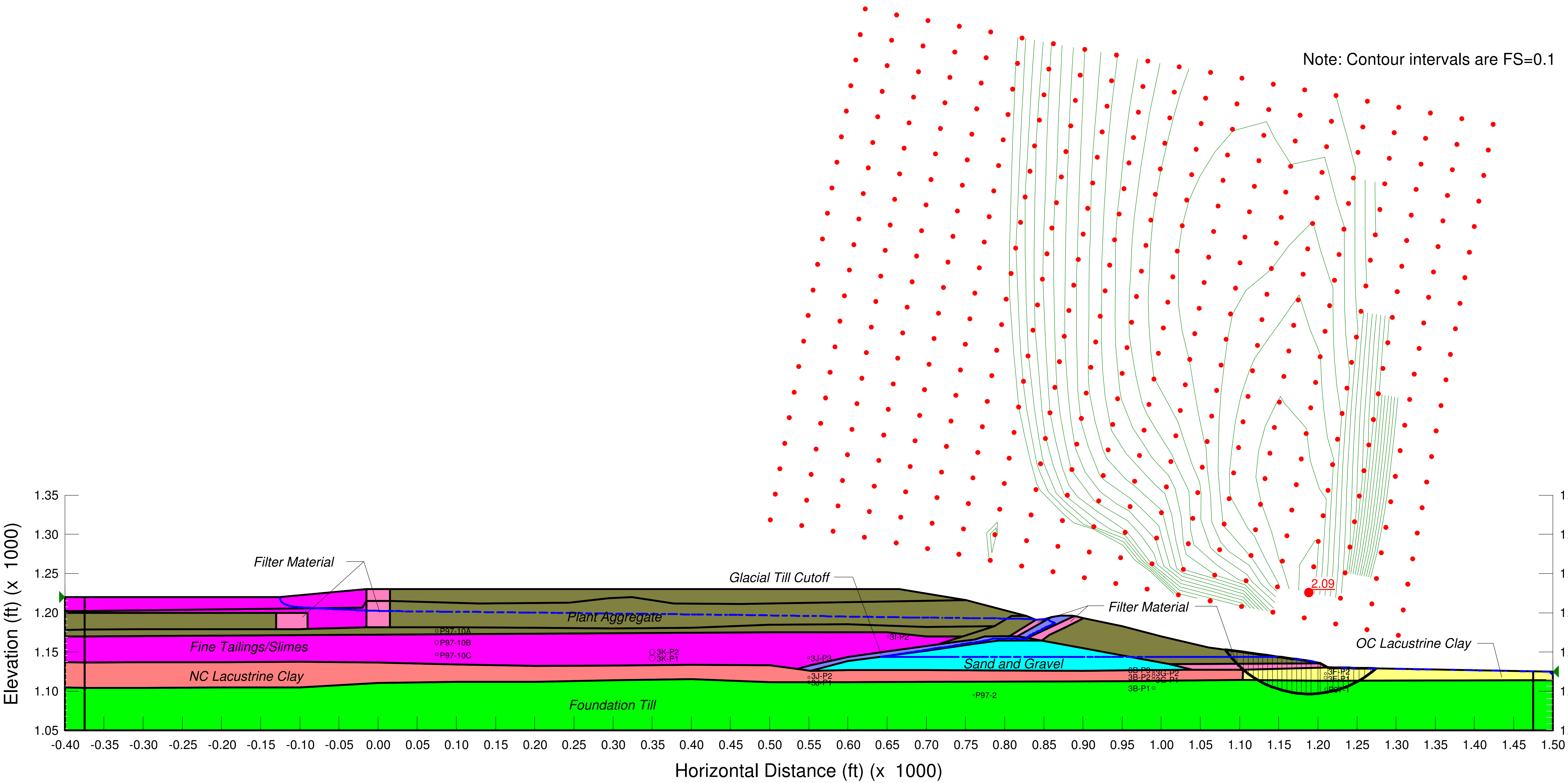
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Toe
File Name: D1_S2840_E1230_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.00



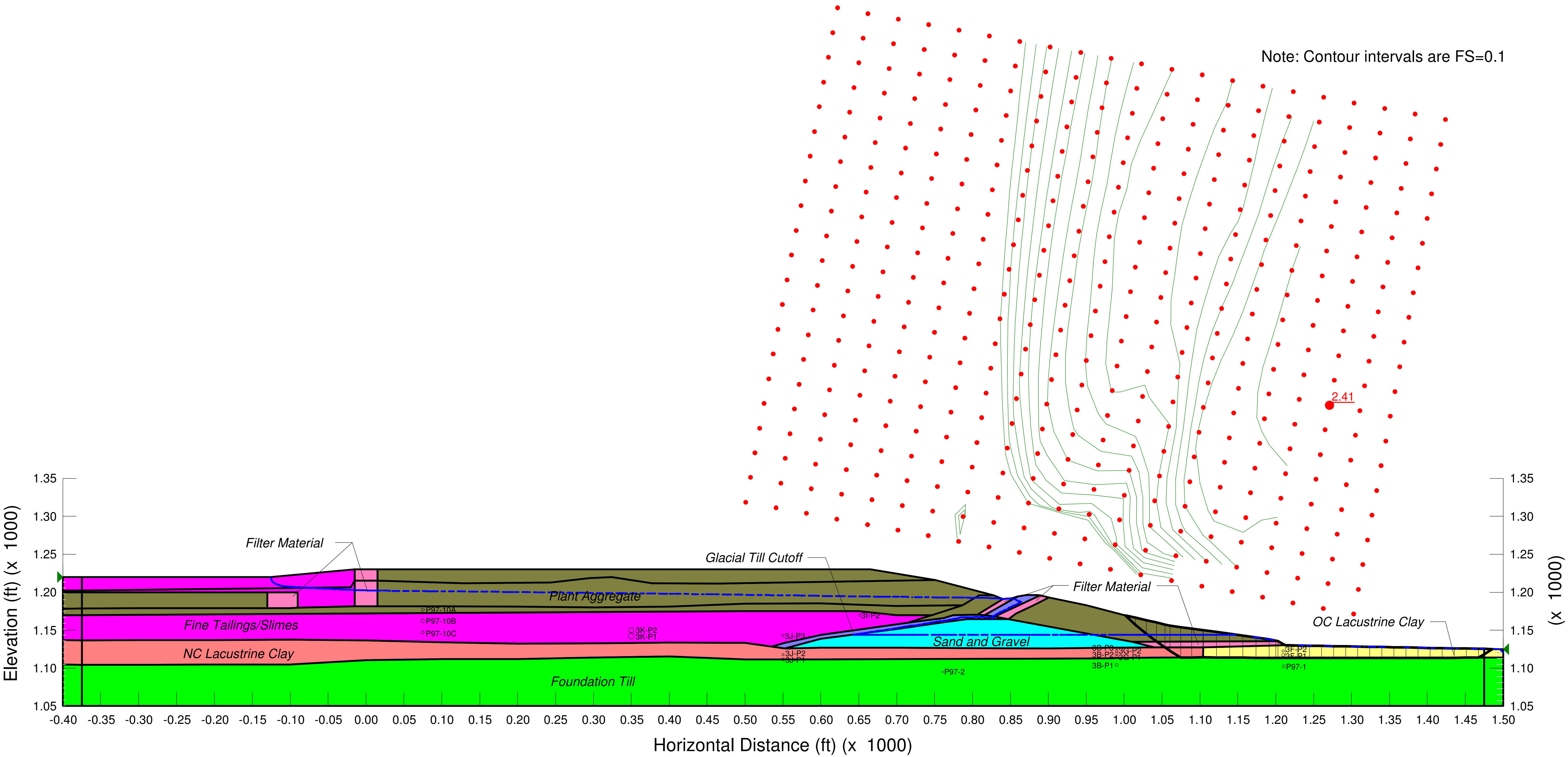
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Block
File Name: D1_S2840_E1230_ESSA_LC3_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.83



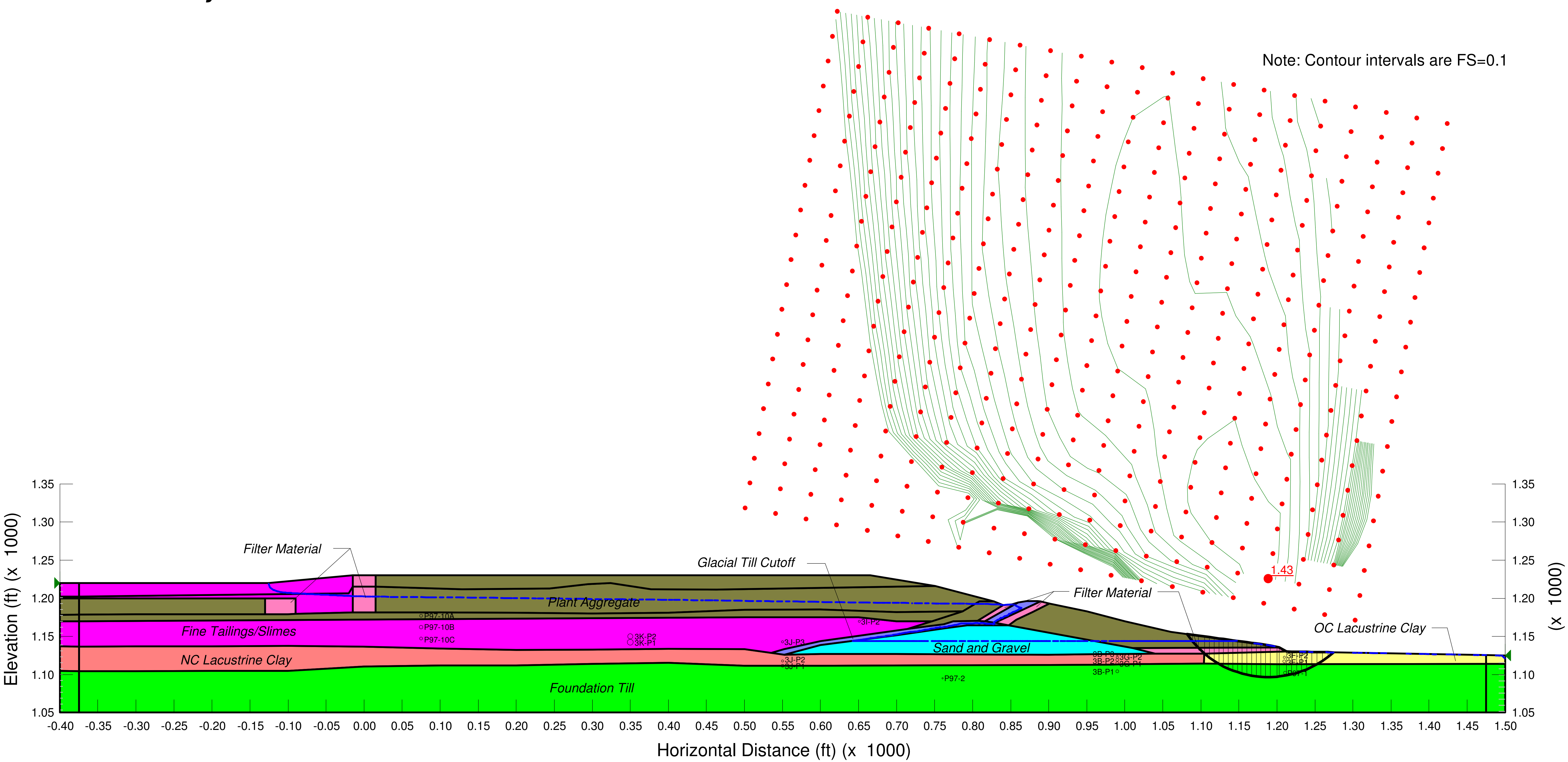
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Toe
File Name: D1_S2840_E1230_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.09



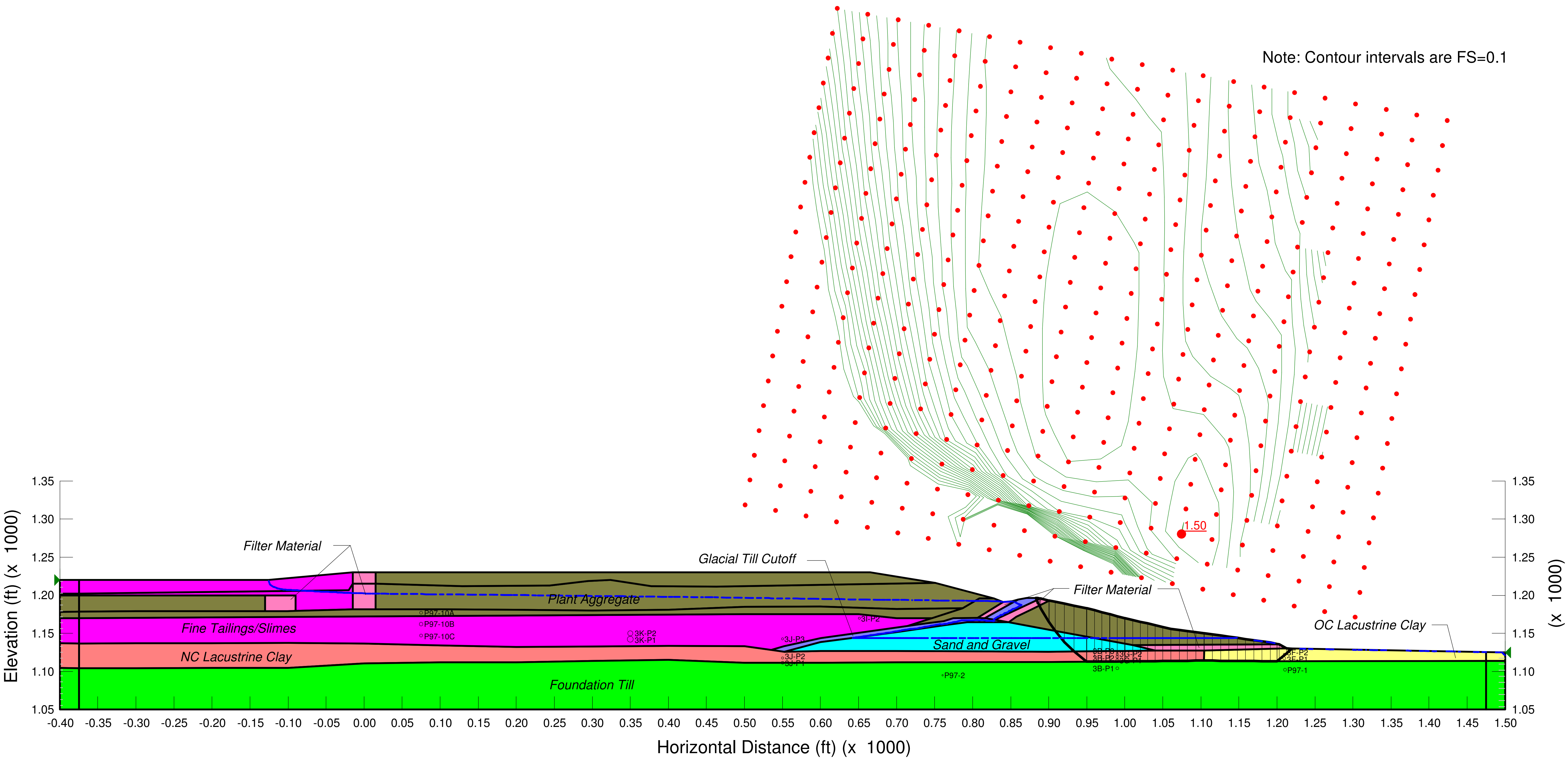
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Block
File Name: D1_S2840_E1230_ESSA_LC4_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.41



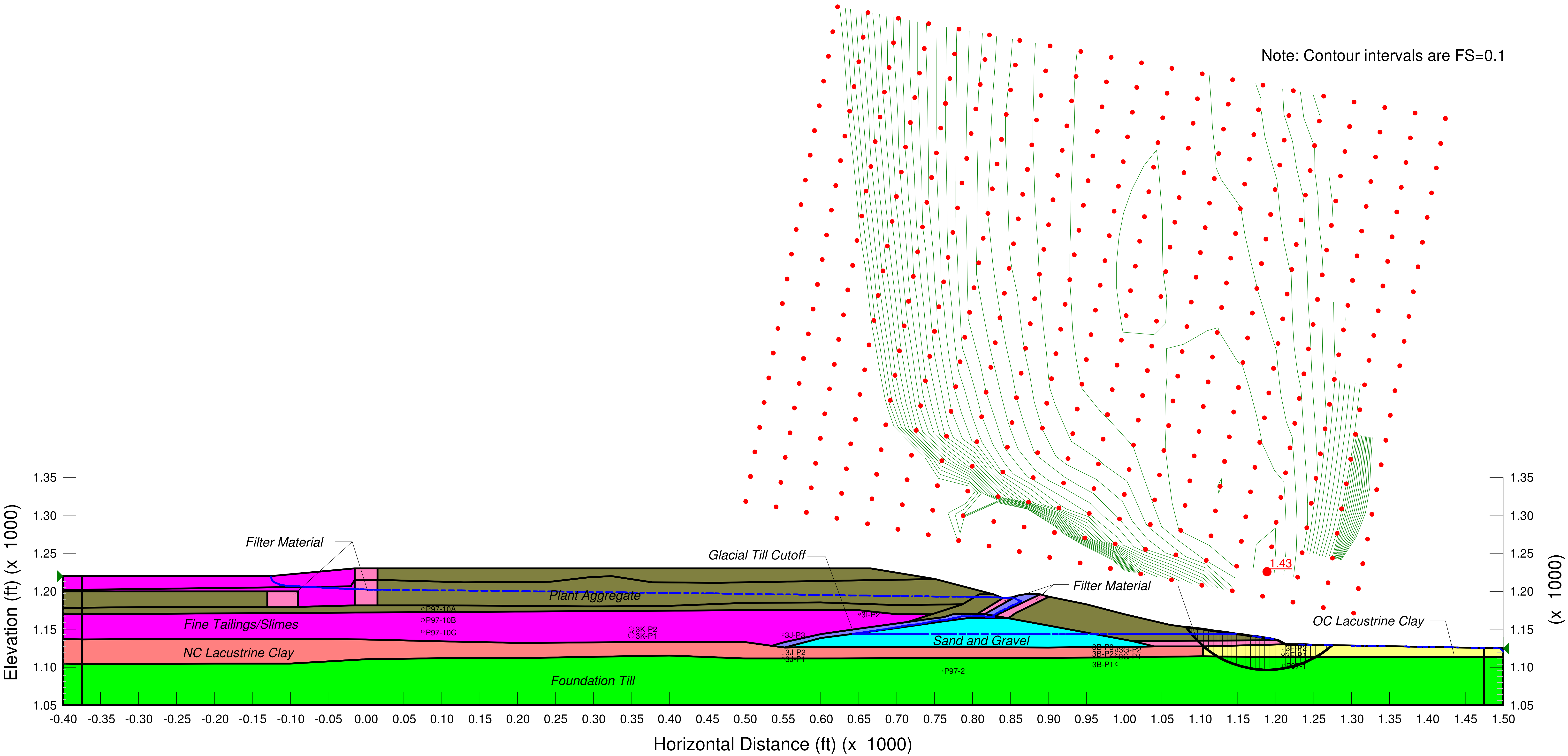
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D1_S2840_E1230_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.43



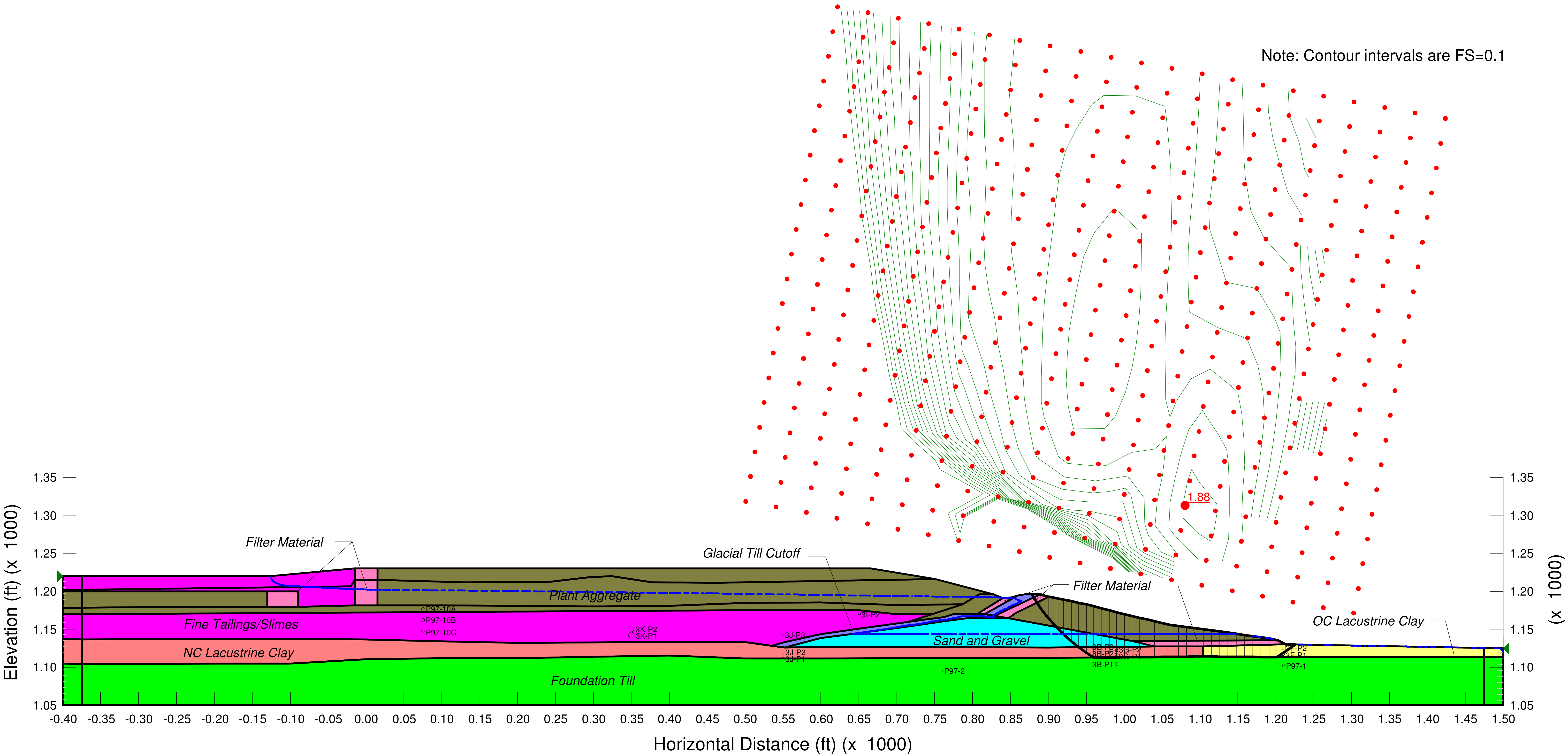
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D1_S2840_E1230_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.50



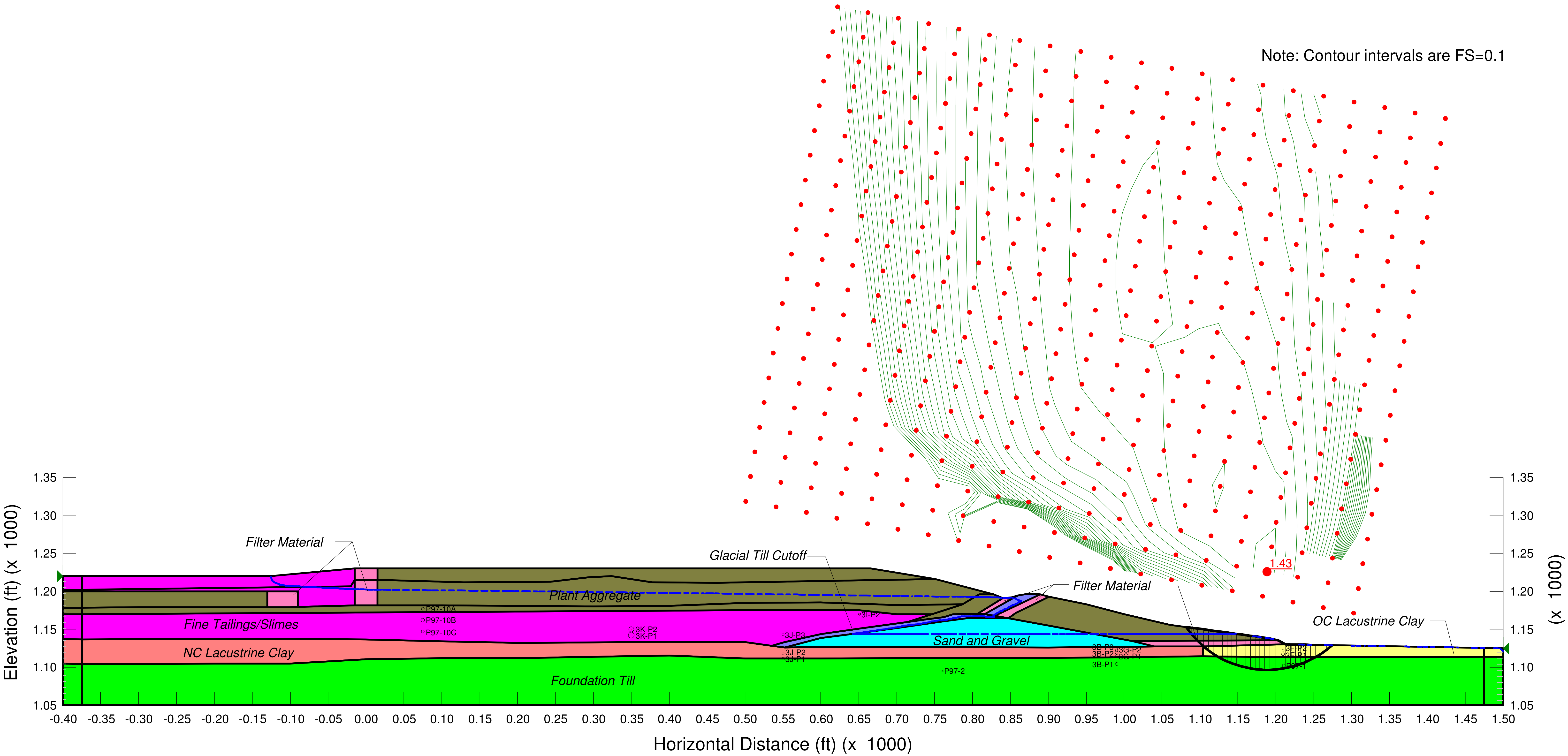
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D1_S2840_E1230_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D1_S2840_E1230_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.88



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D1_S2840_E1230_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.1, FM Block
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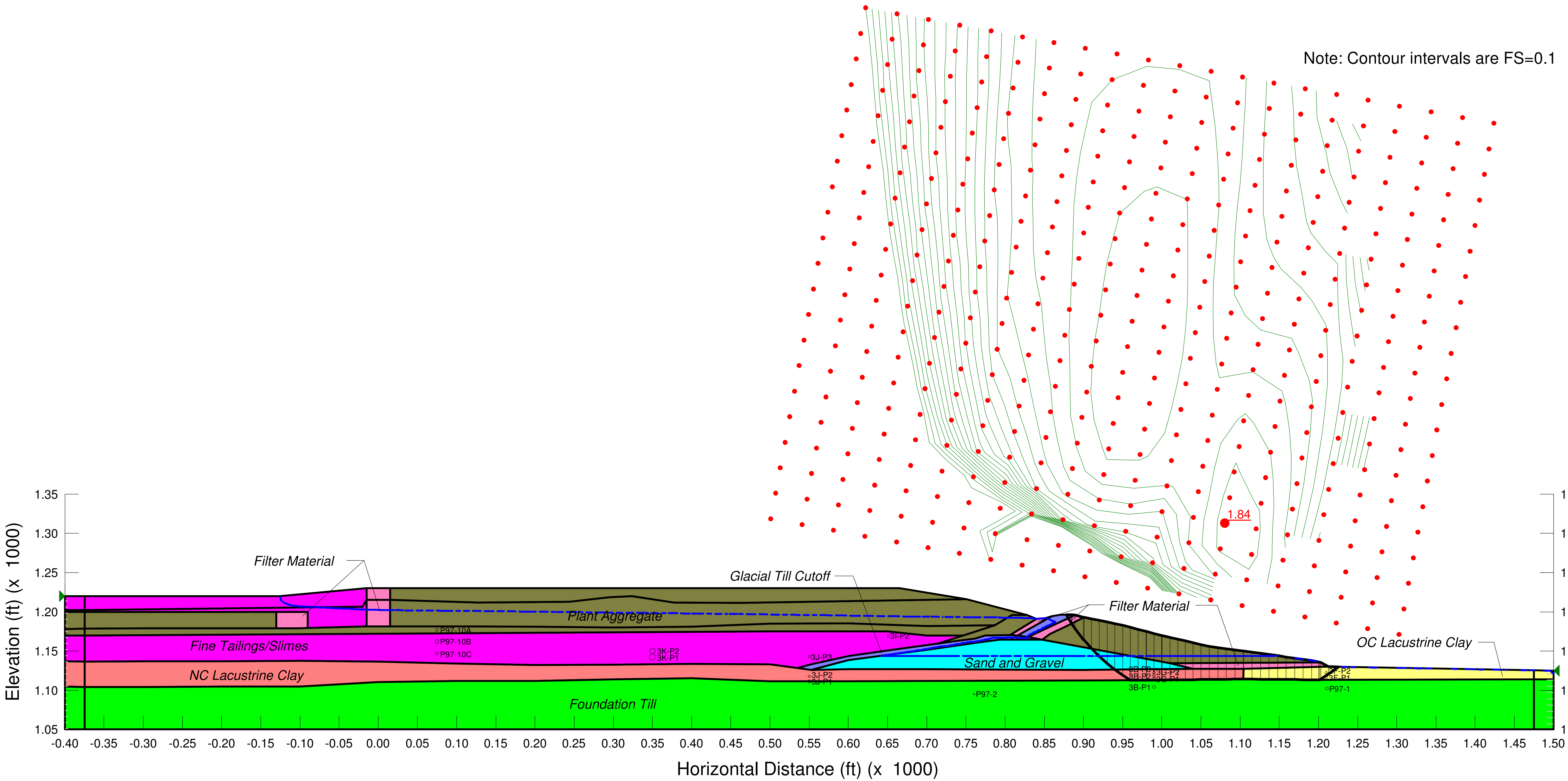
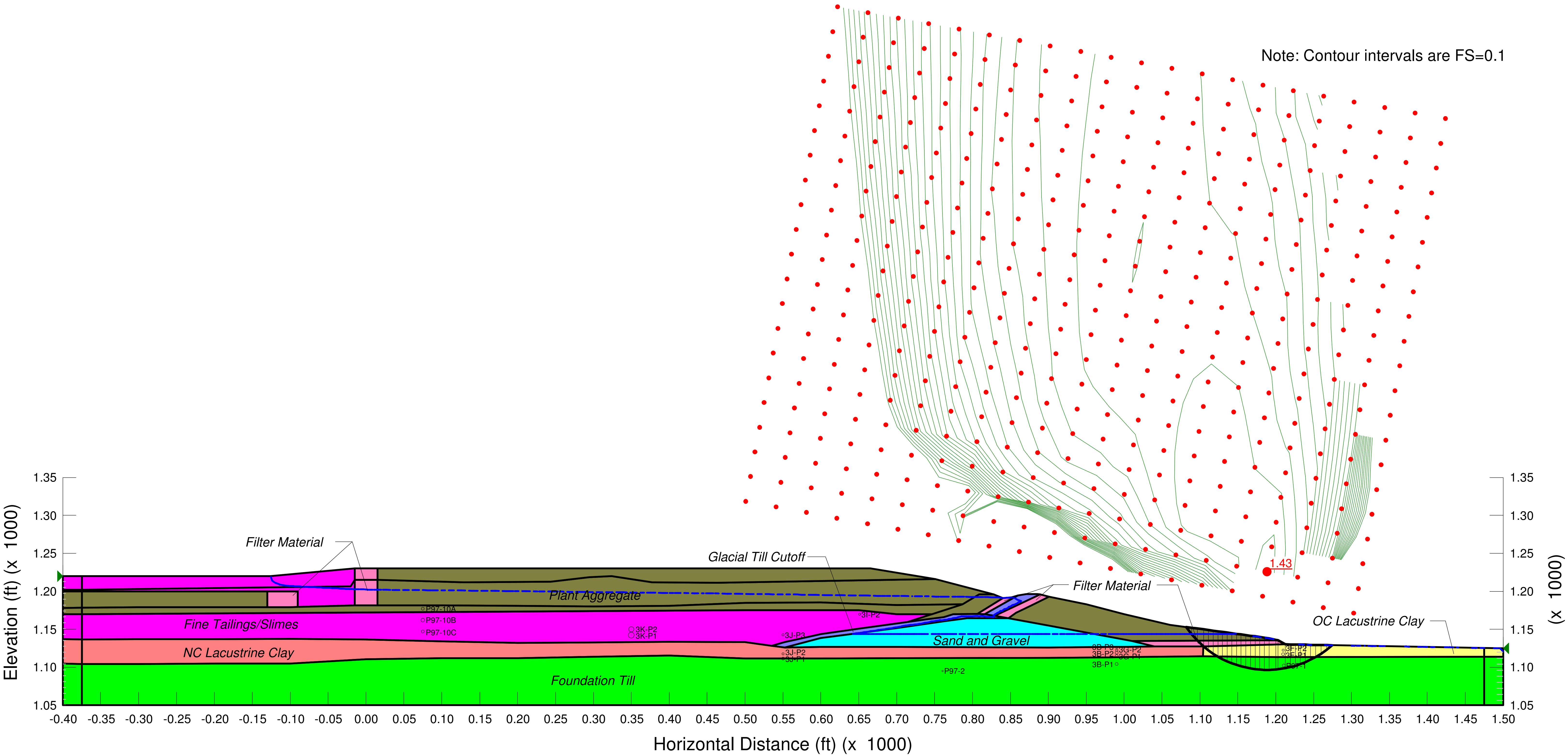
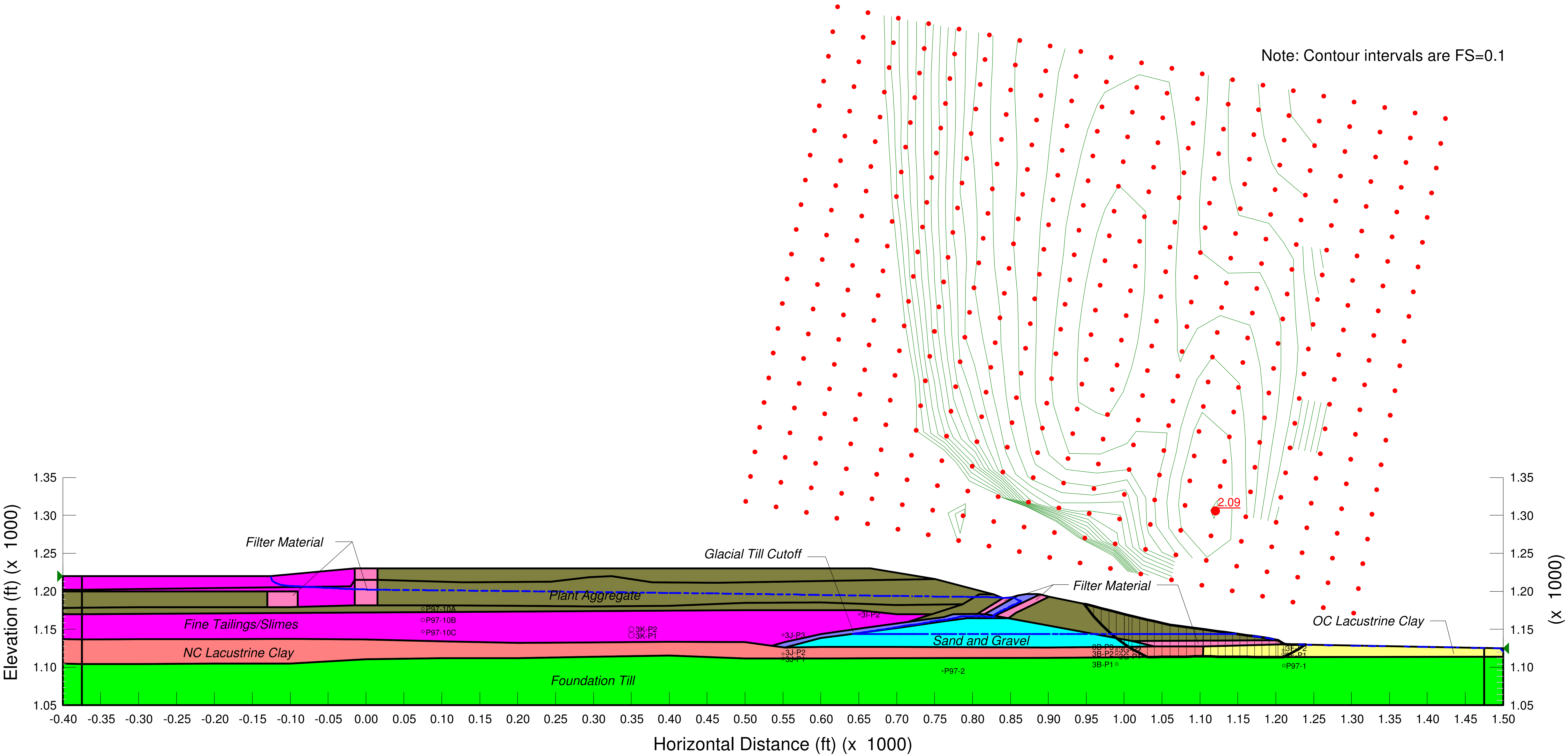
Last Saved Date: 11/17/2008
Factor of Safety: 1.84



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D1_S2840_E1230_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.43

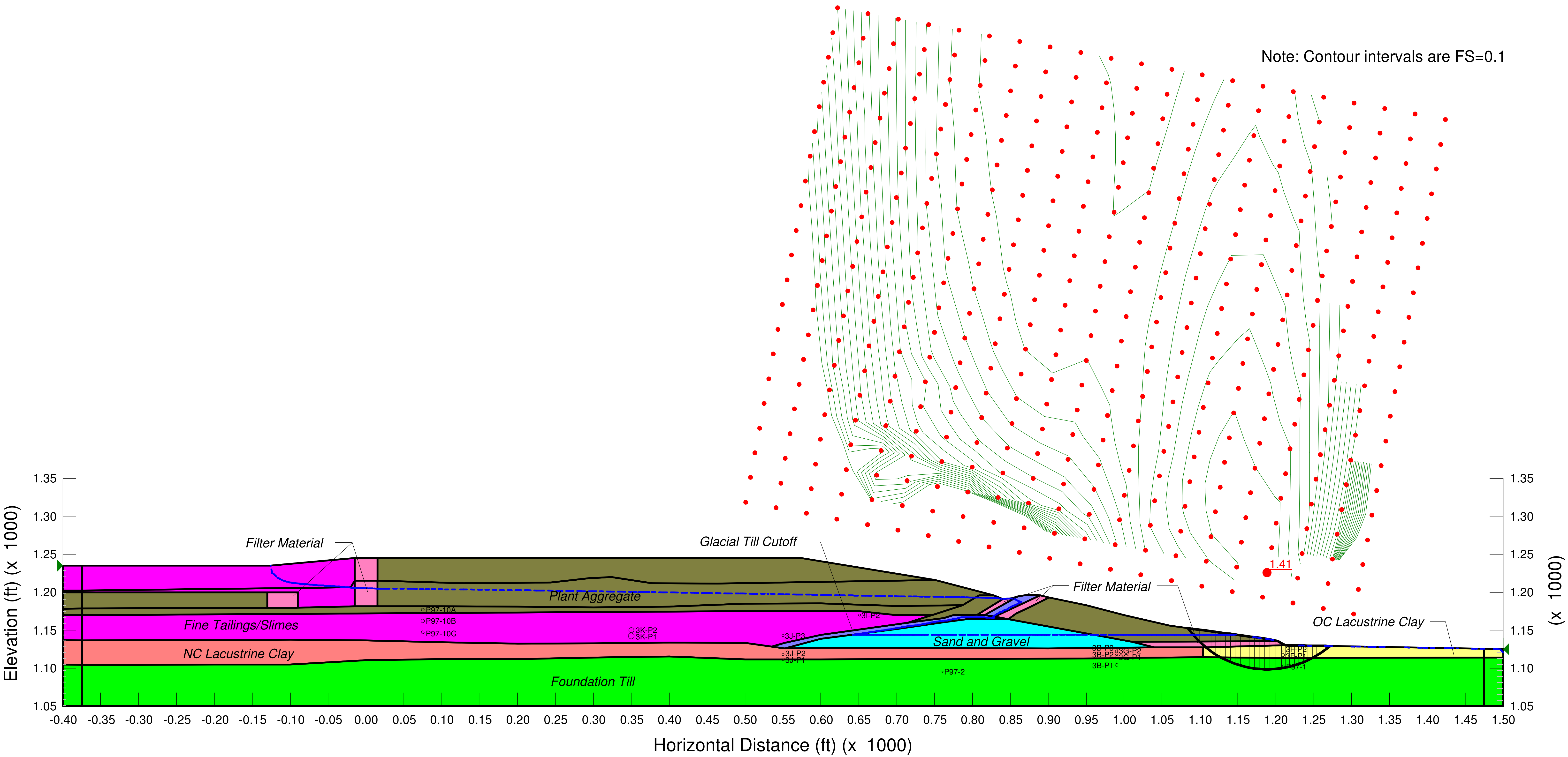


Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D1_S2840_E1230_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.09

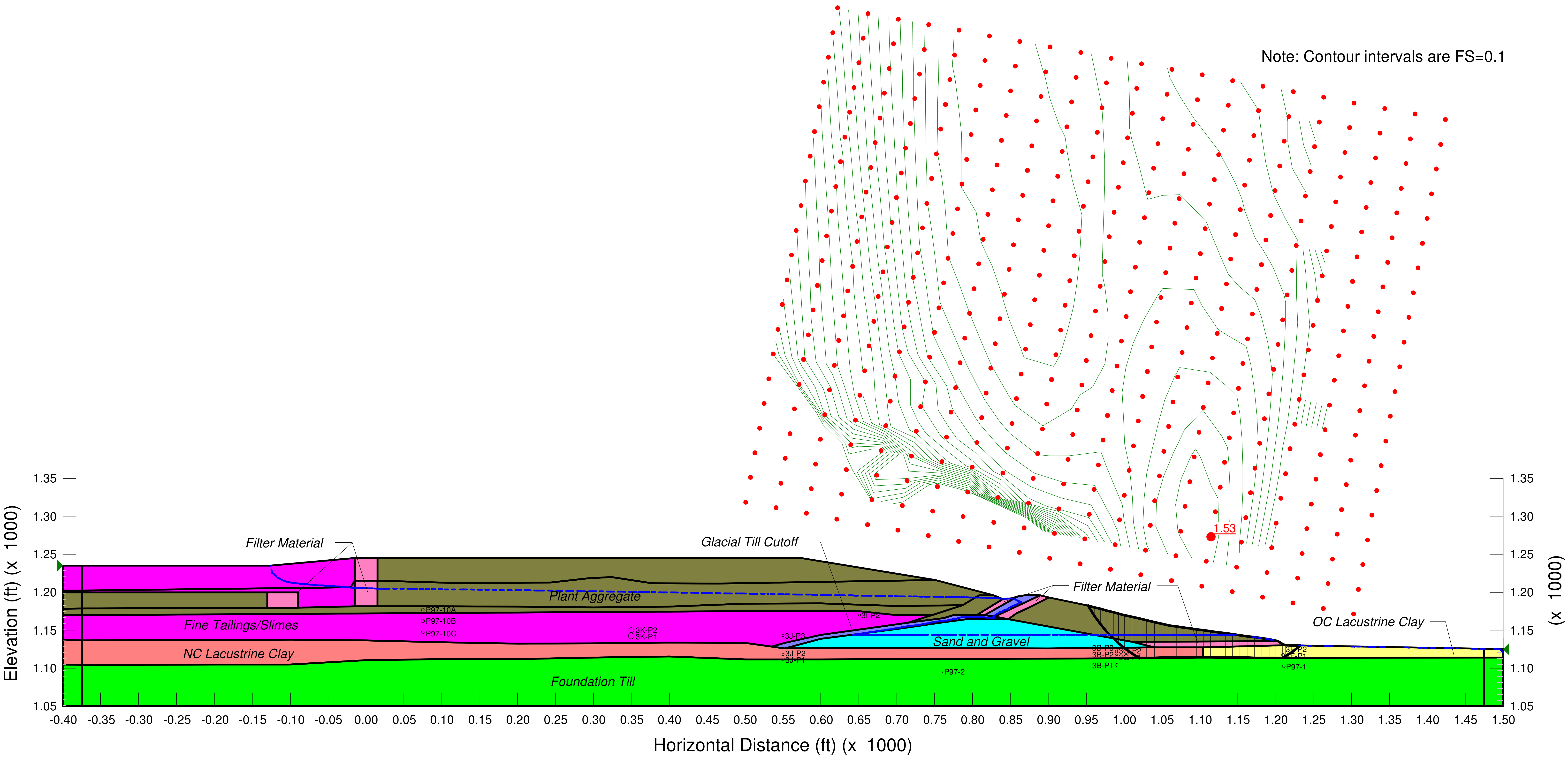


Proposed Geometry El. 1,245 feet

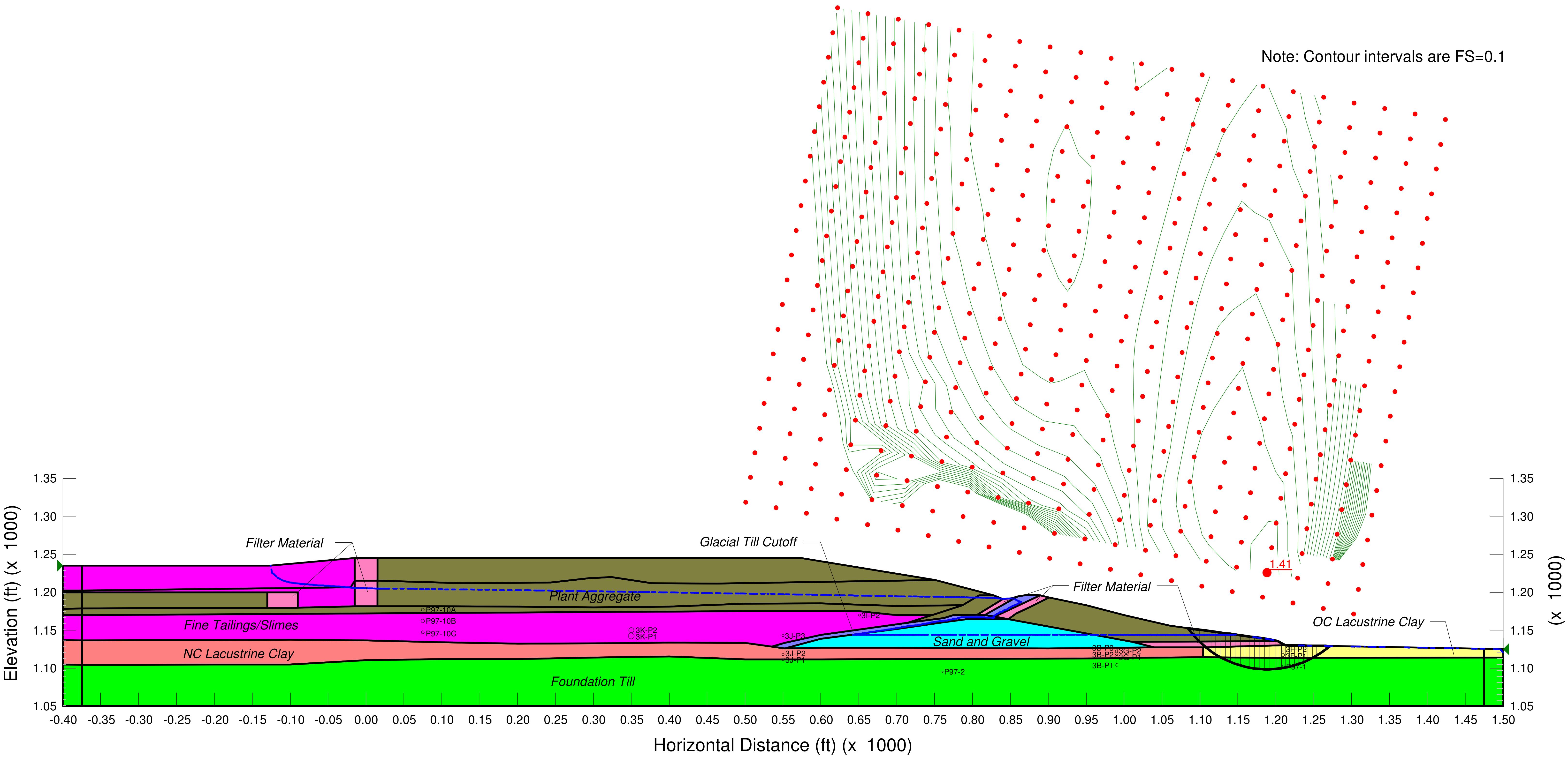
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D1_S2840_E1245_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.41



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D1_S2840_E1245_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.53



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.2, FM Toe
_File Name: D1_S2840_E1245_USSA_LC6_FT2_FM1.gsz_
Last Saved Date: 6/19/2009
Factor of Safety: 1.41



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.2, FM Block
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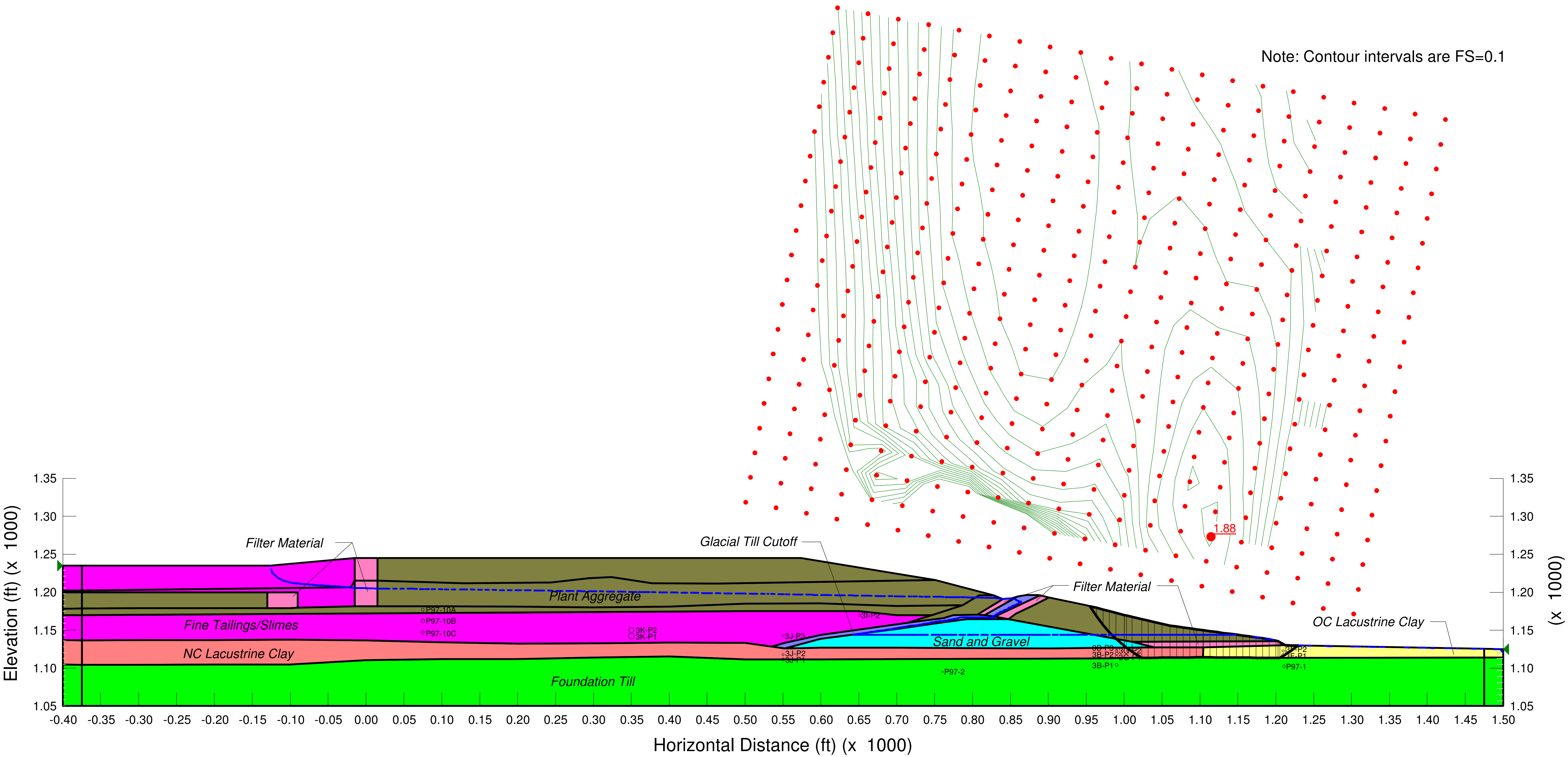
Last Saved Date: 6/19/2009
Factor of Safety: 1.88



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
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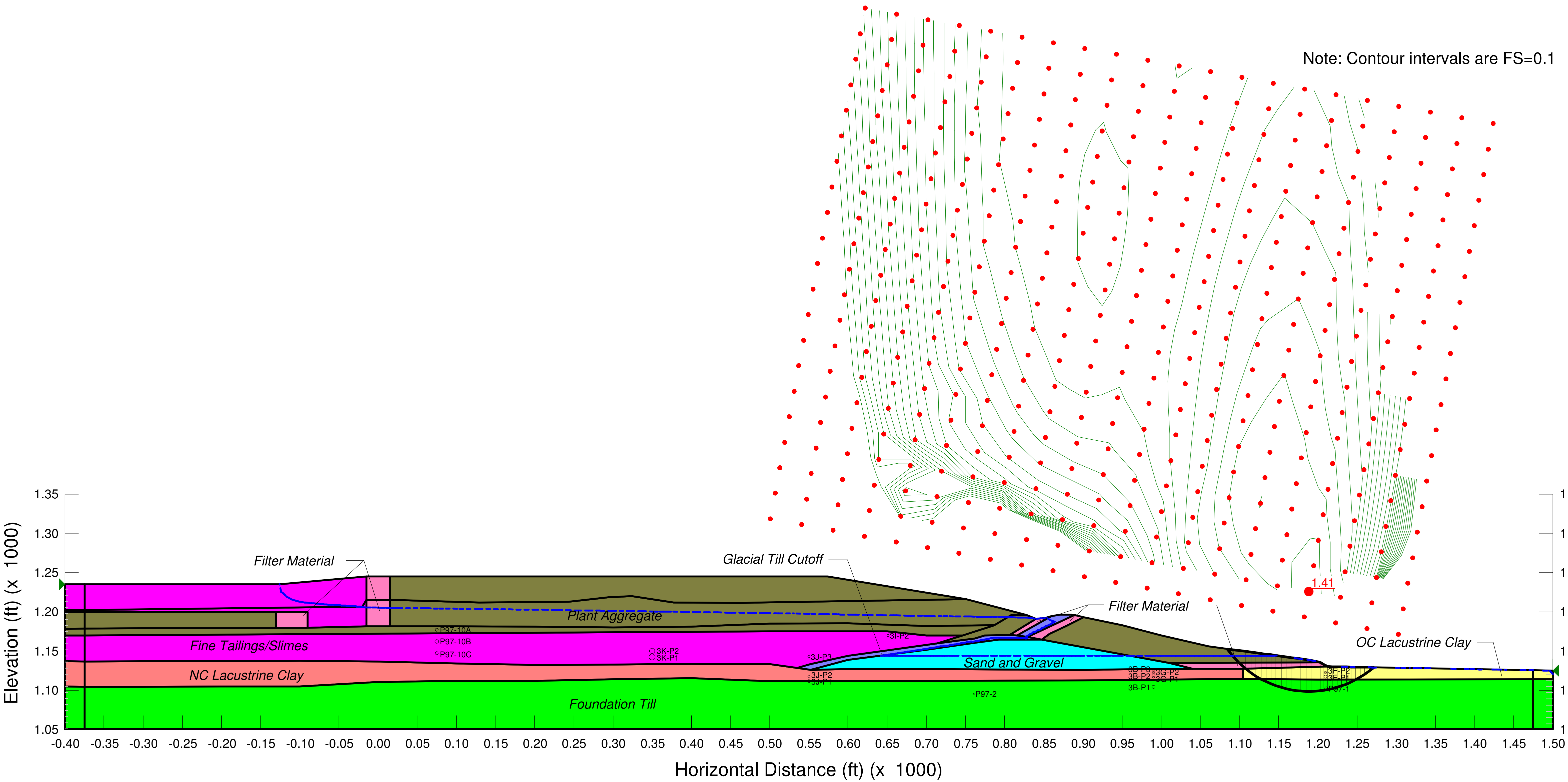
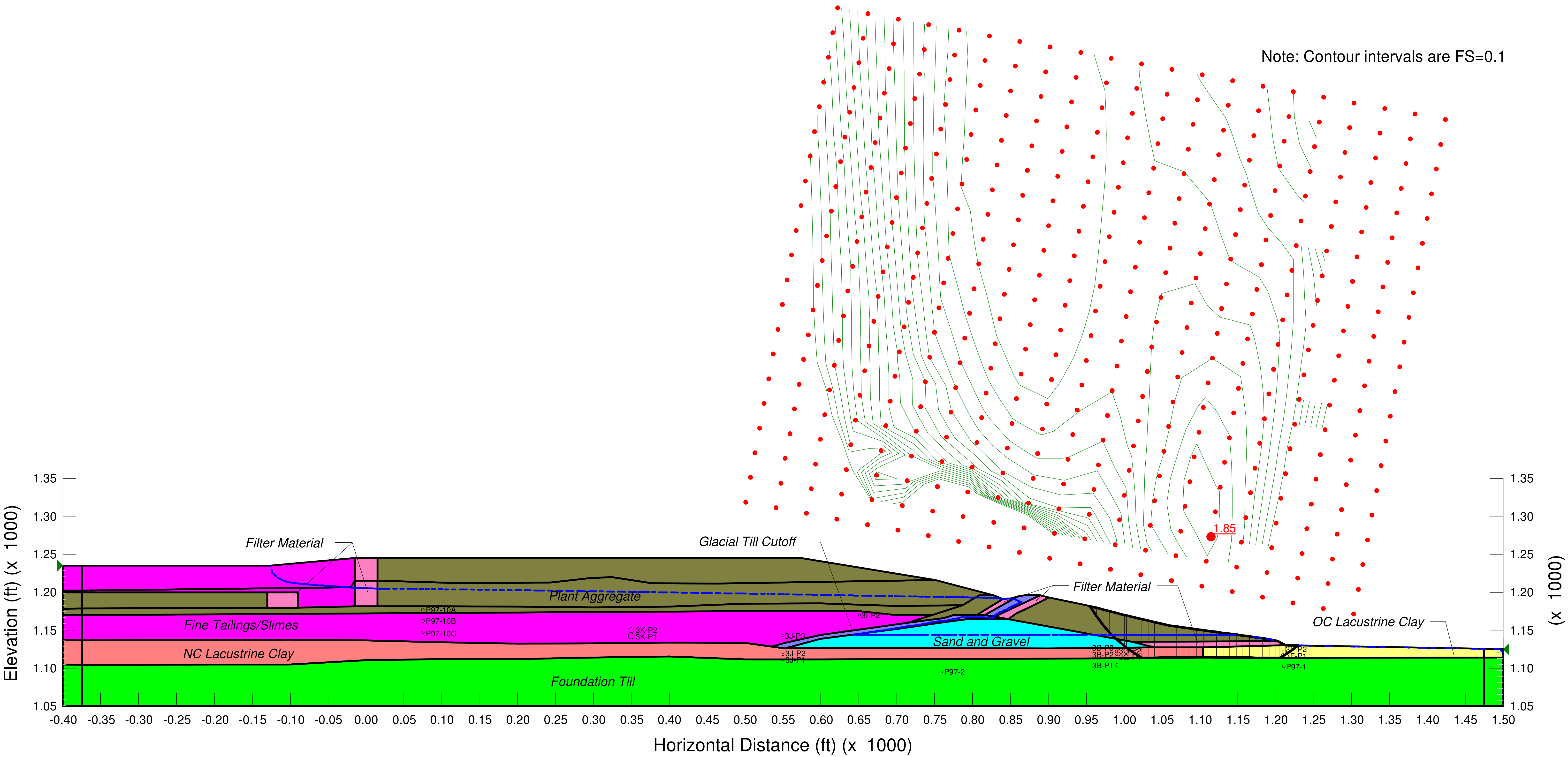
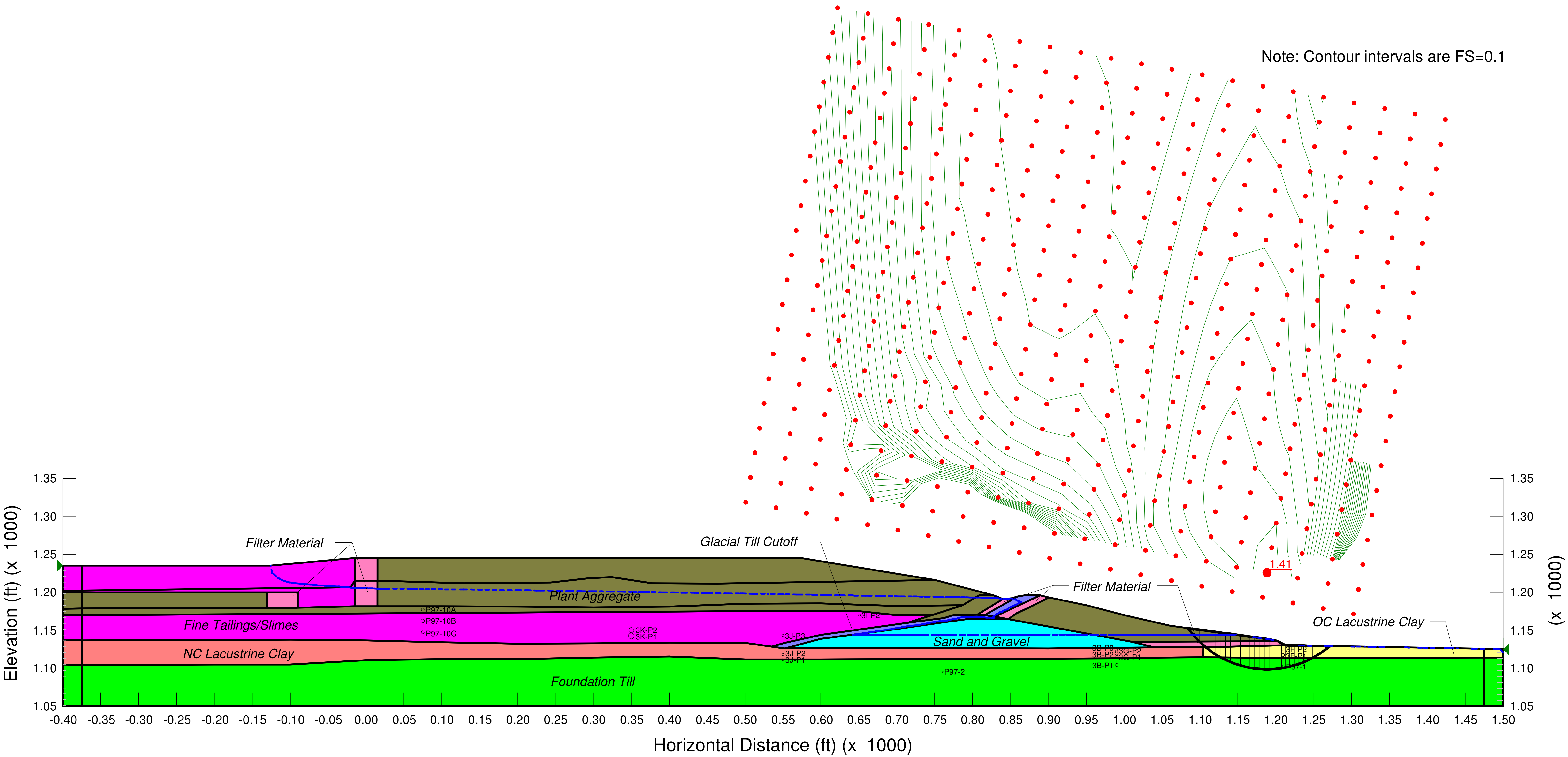
File Name: D1_S2840_E1245_USSA_LC7_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.41



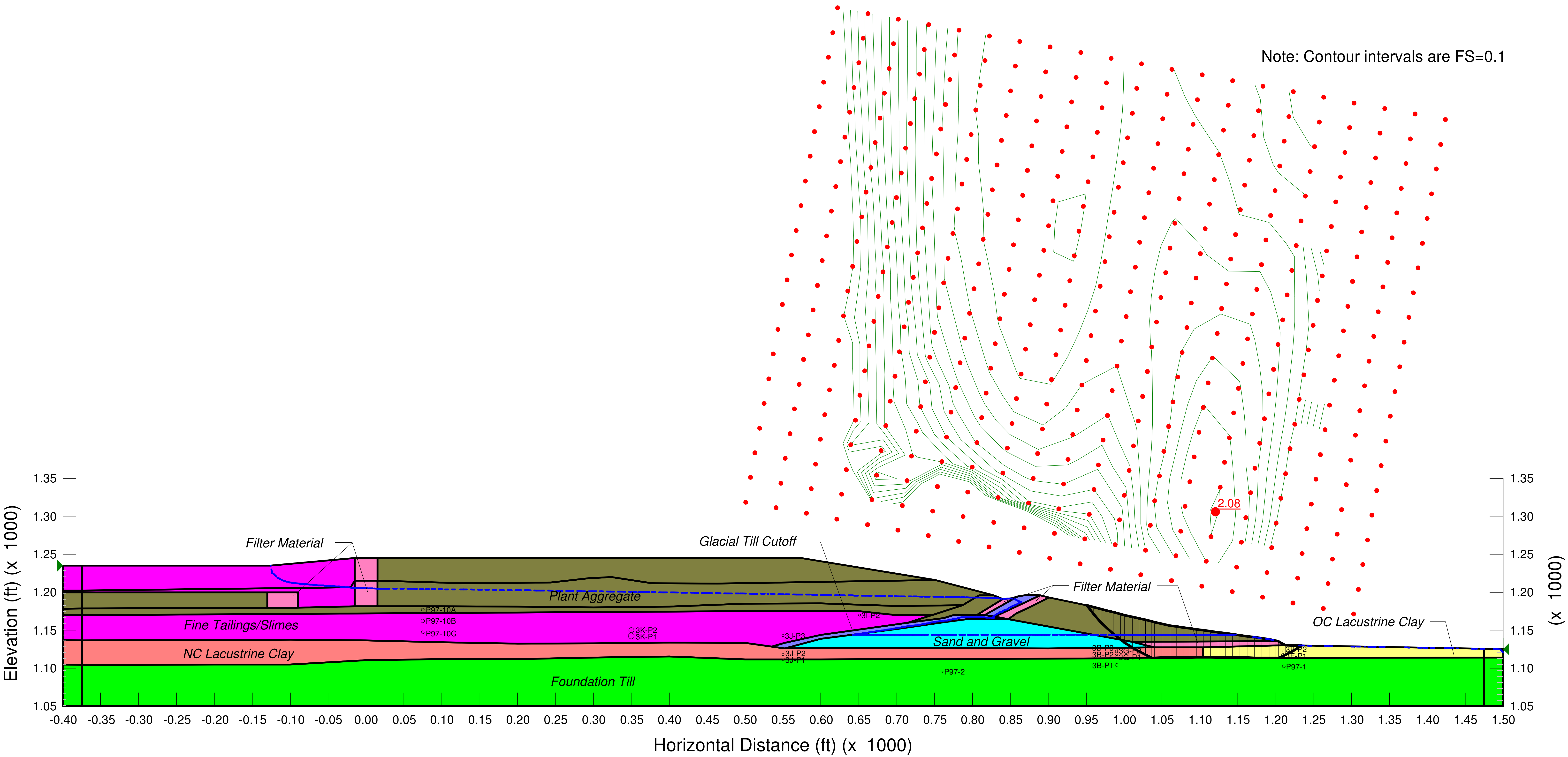
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.2, FM Block
File Name: D1_S2840_E1245_USSA_LC7_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.85



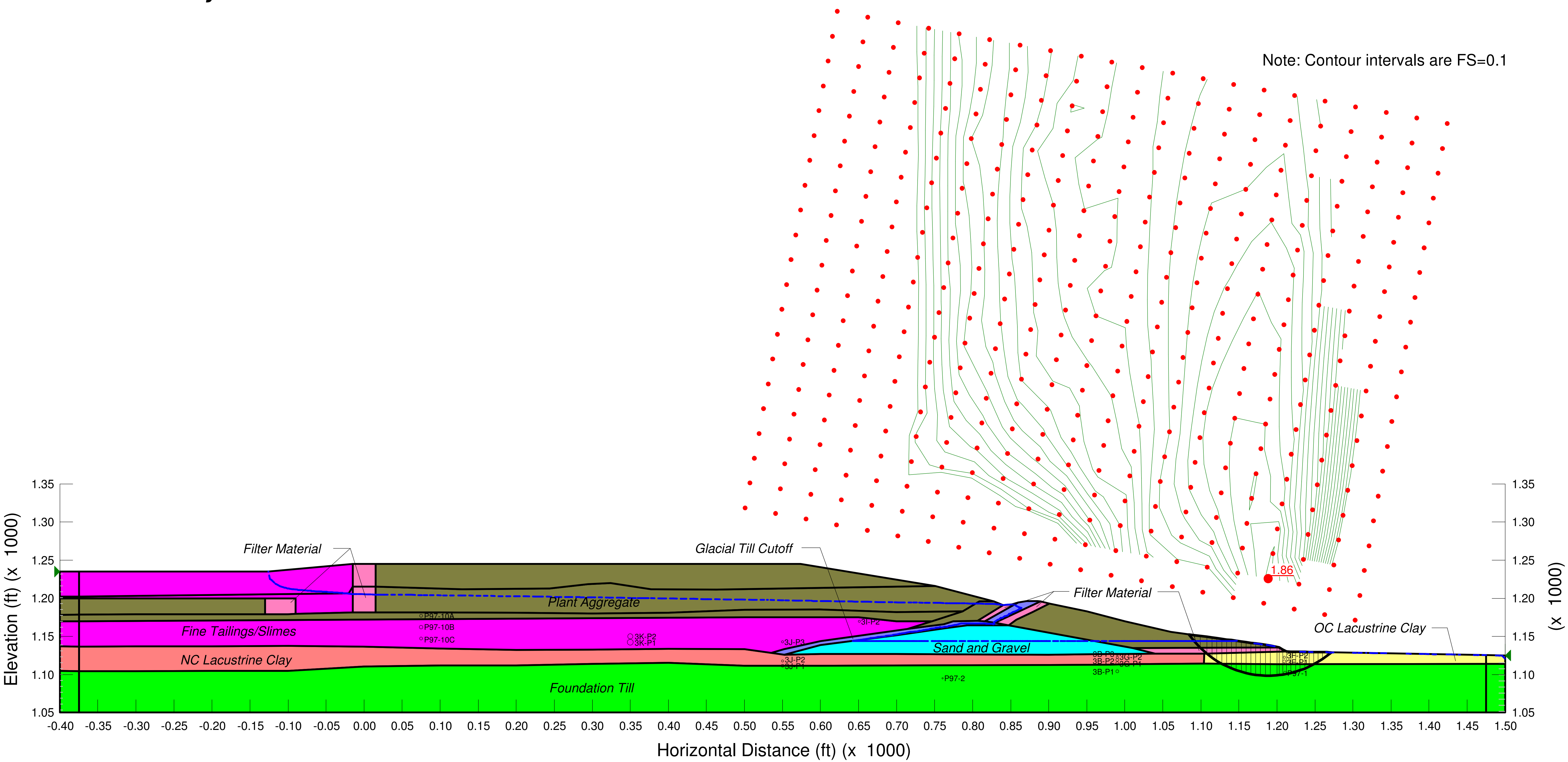
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D1_S2840_E1245_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.41



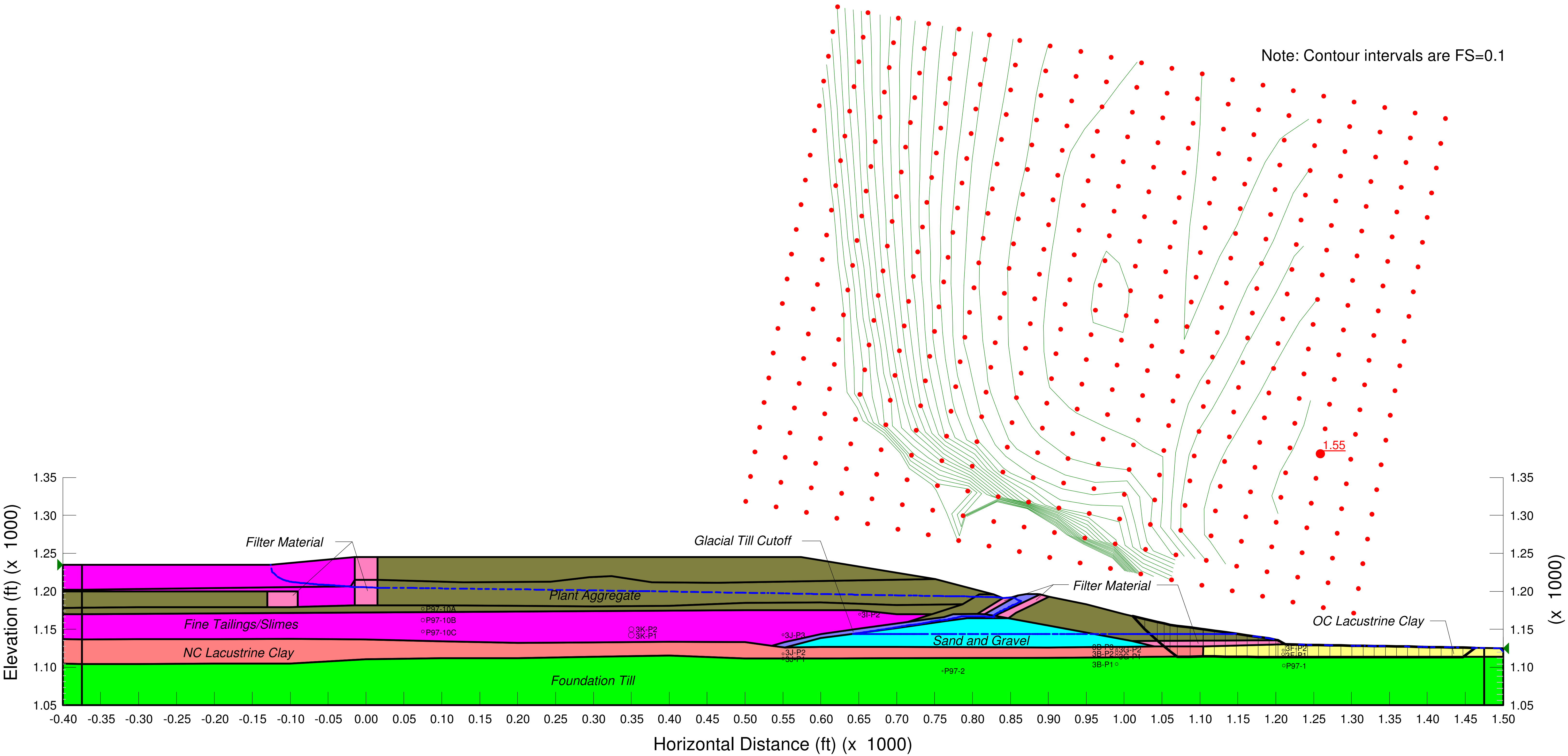
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D1_S2840_E1245_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.08



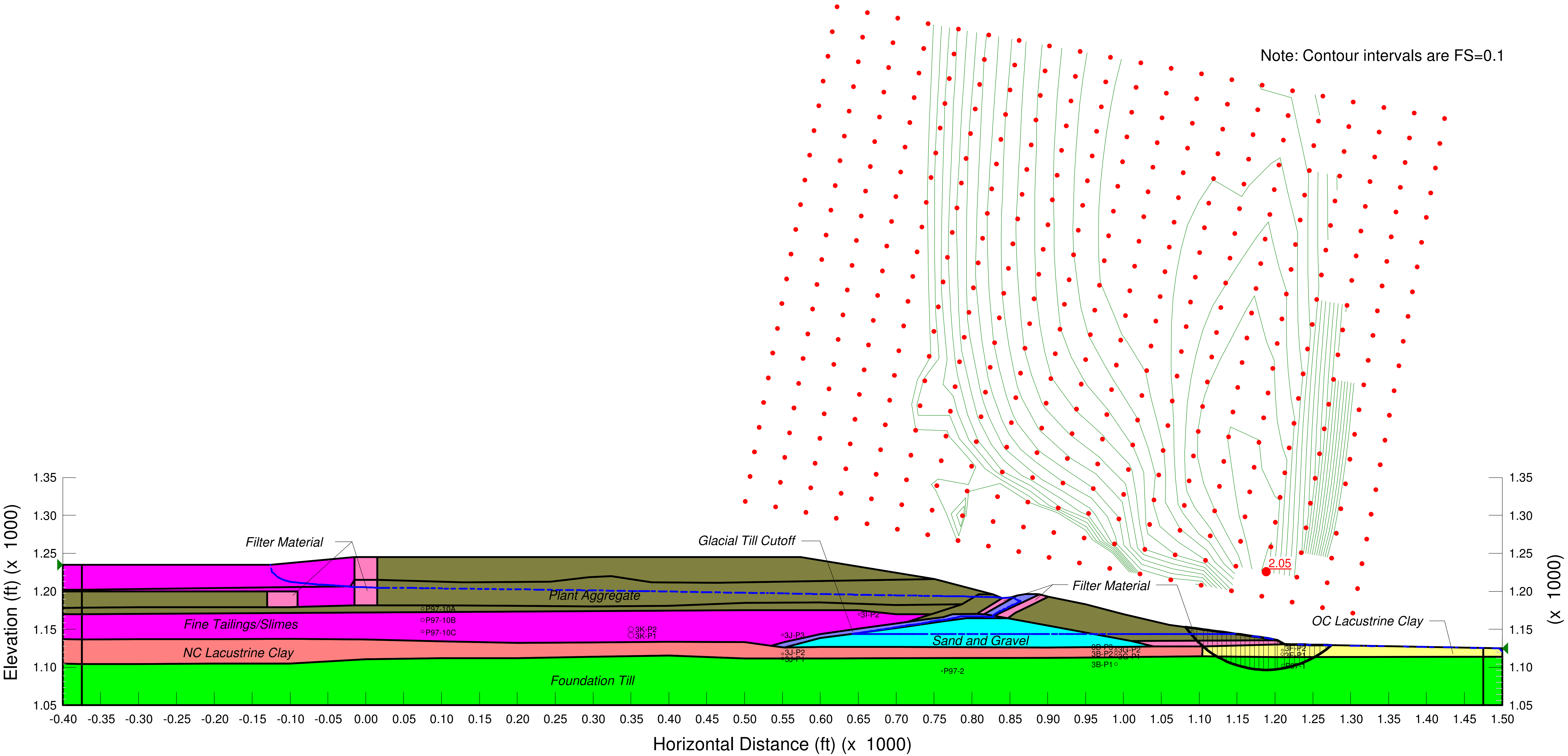
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Toe
File Name: D1_S2840_E1245_ESSA_LC1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.86



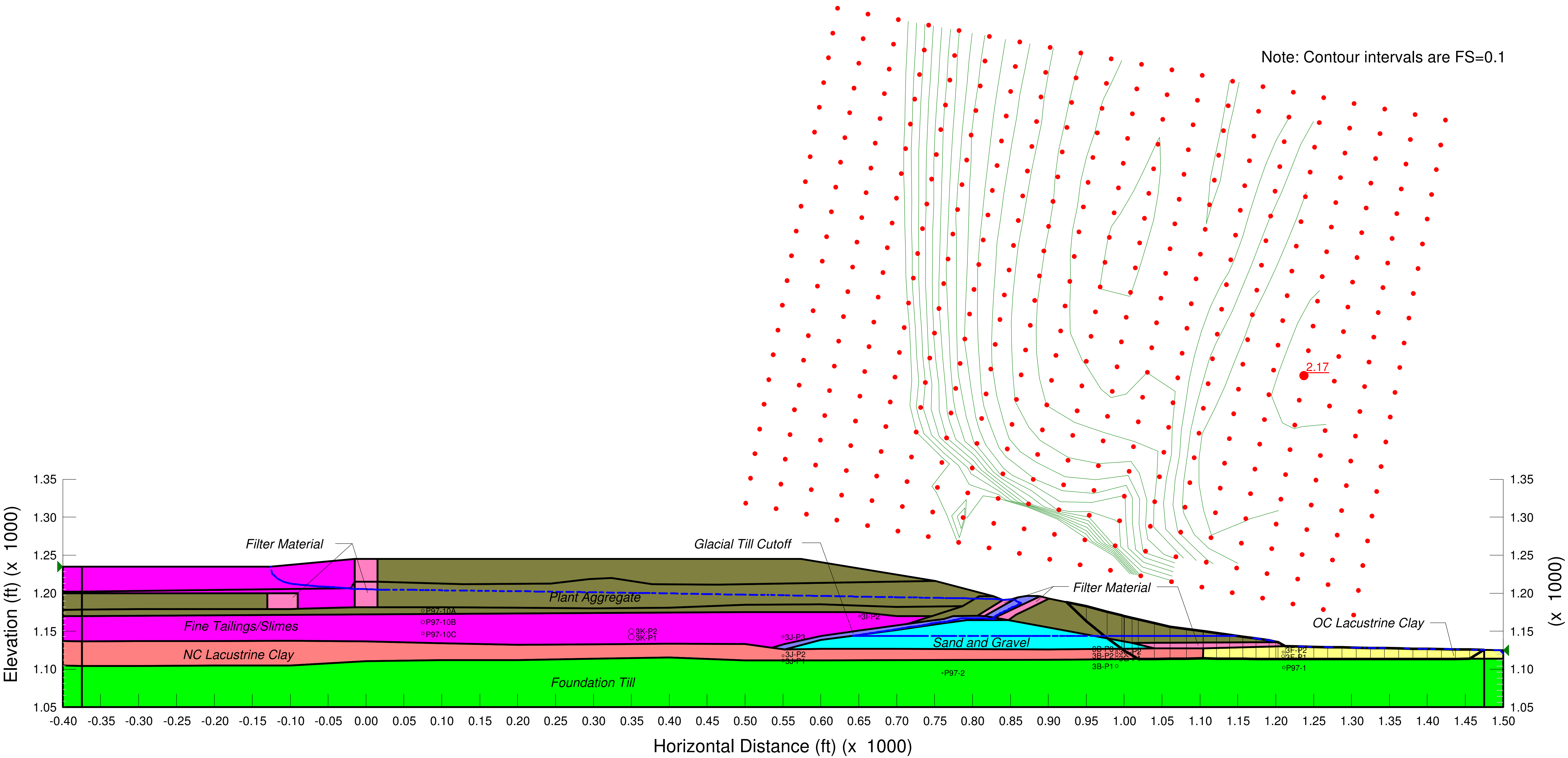
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Block
File Name: D1_S2840_E1245_ESSA_LC1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.55



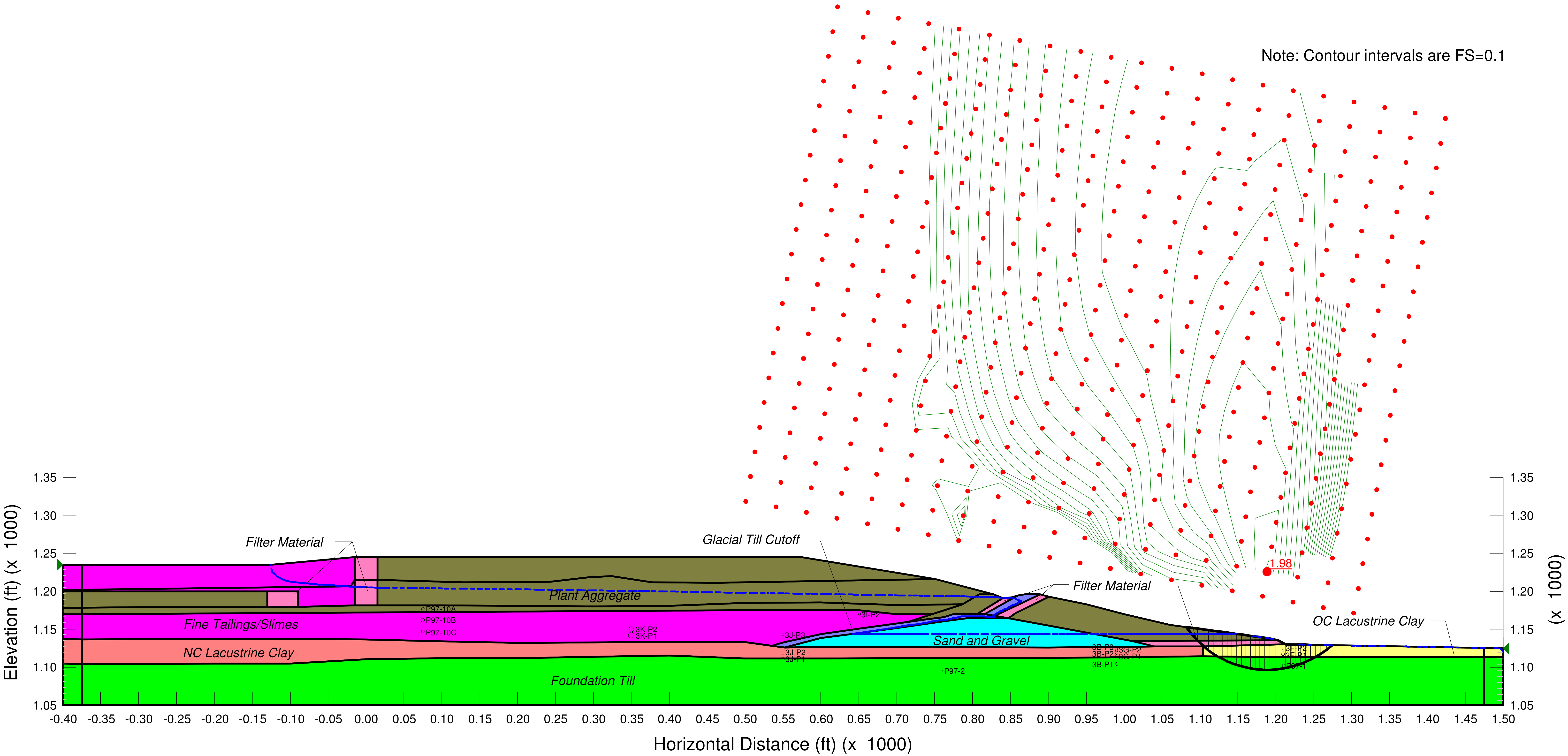
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Toe
File Name: D1_S2840_E1245_ESSA_LC2_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.05



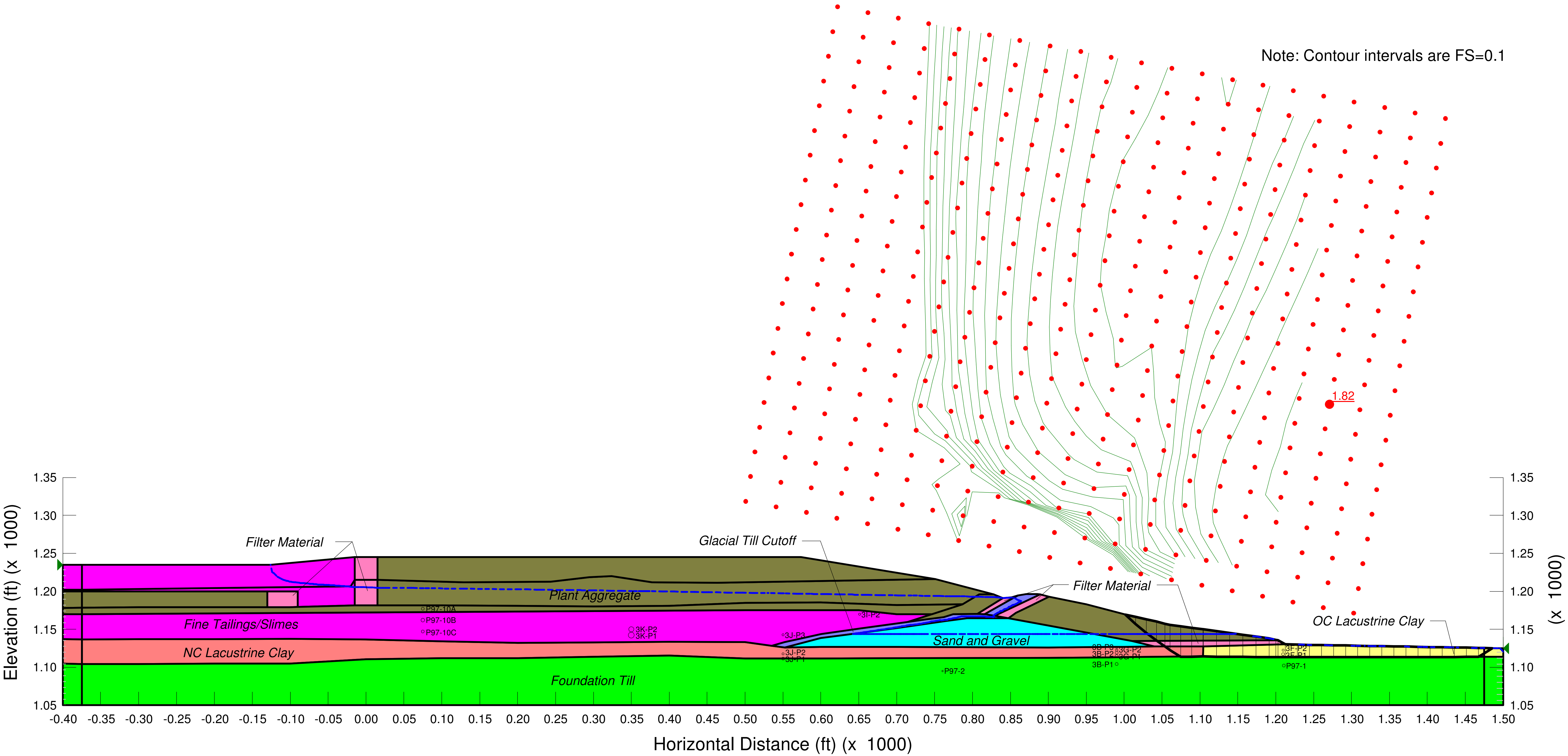
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Block
File Name: D1_S2840_E1245_ESSA_LC2_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.17



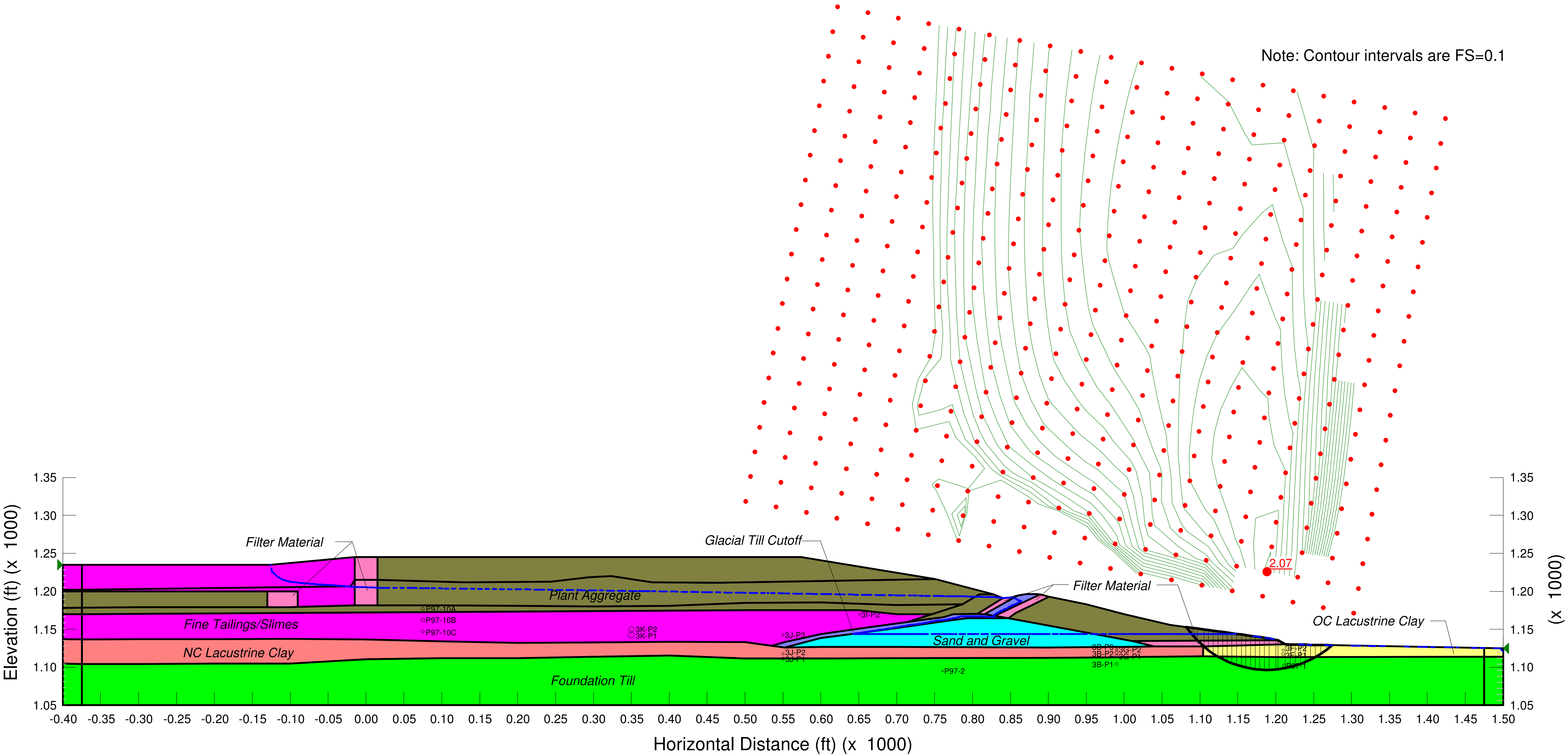
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Toe
File Name: D1_S2840_E1245_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.98



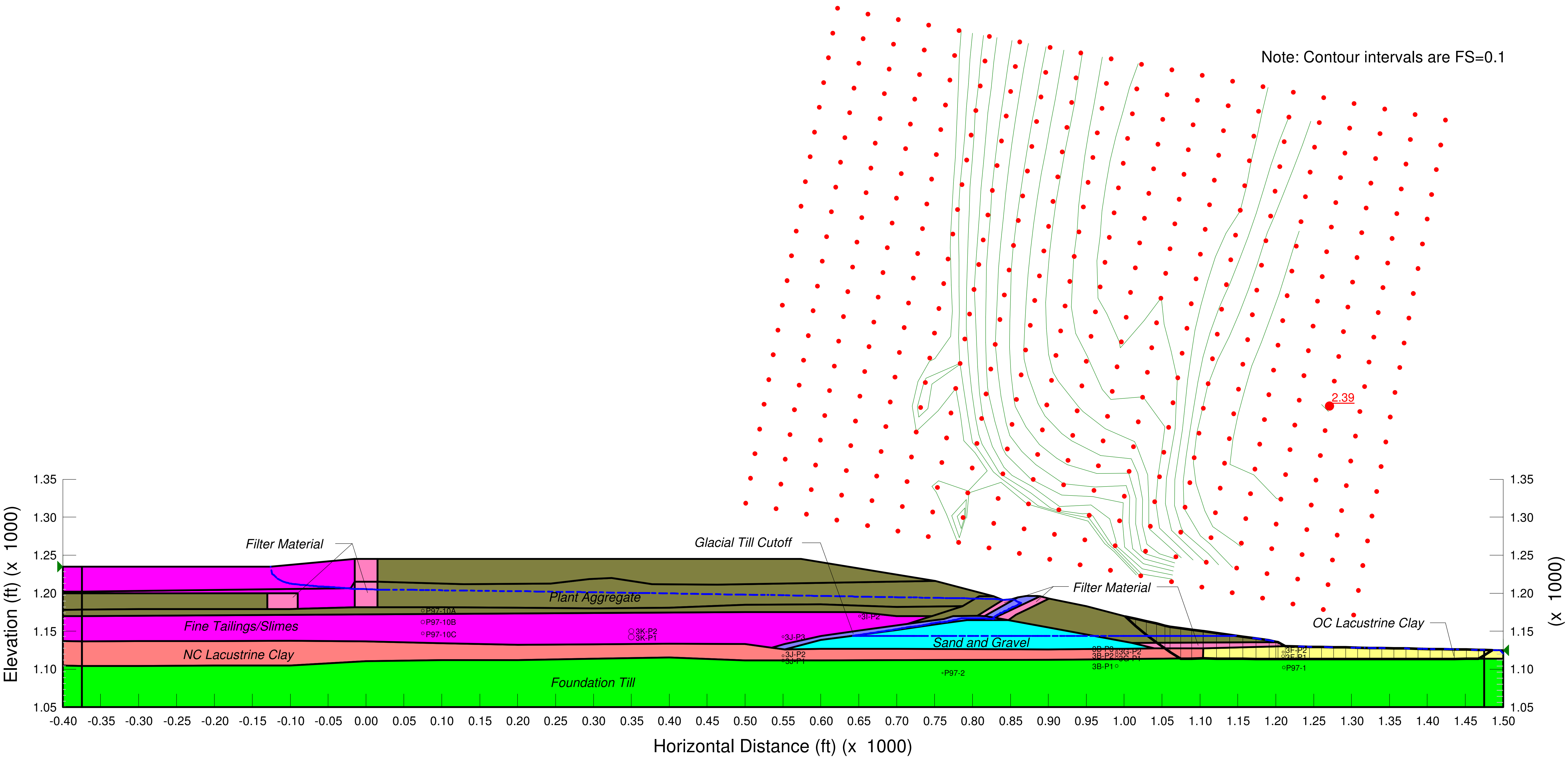
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Block
File Name: D1_S2840_E1245_ESSA_LC3_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.82



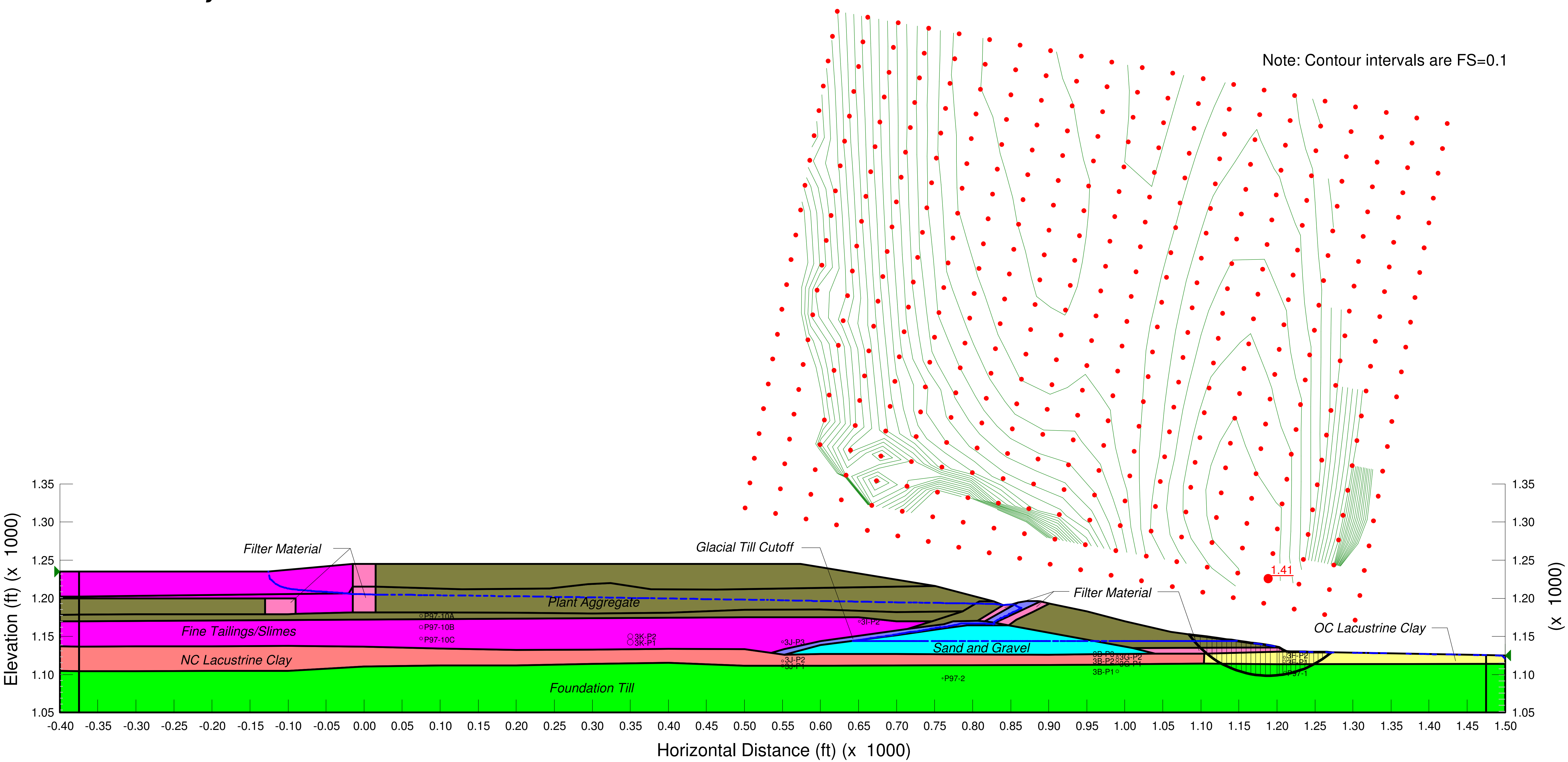
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Toe
File Name: D1_S2840_E1245_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.07



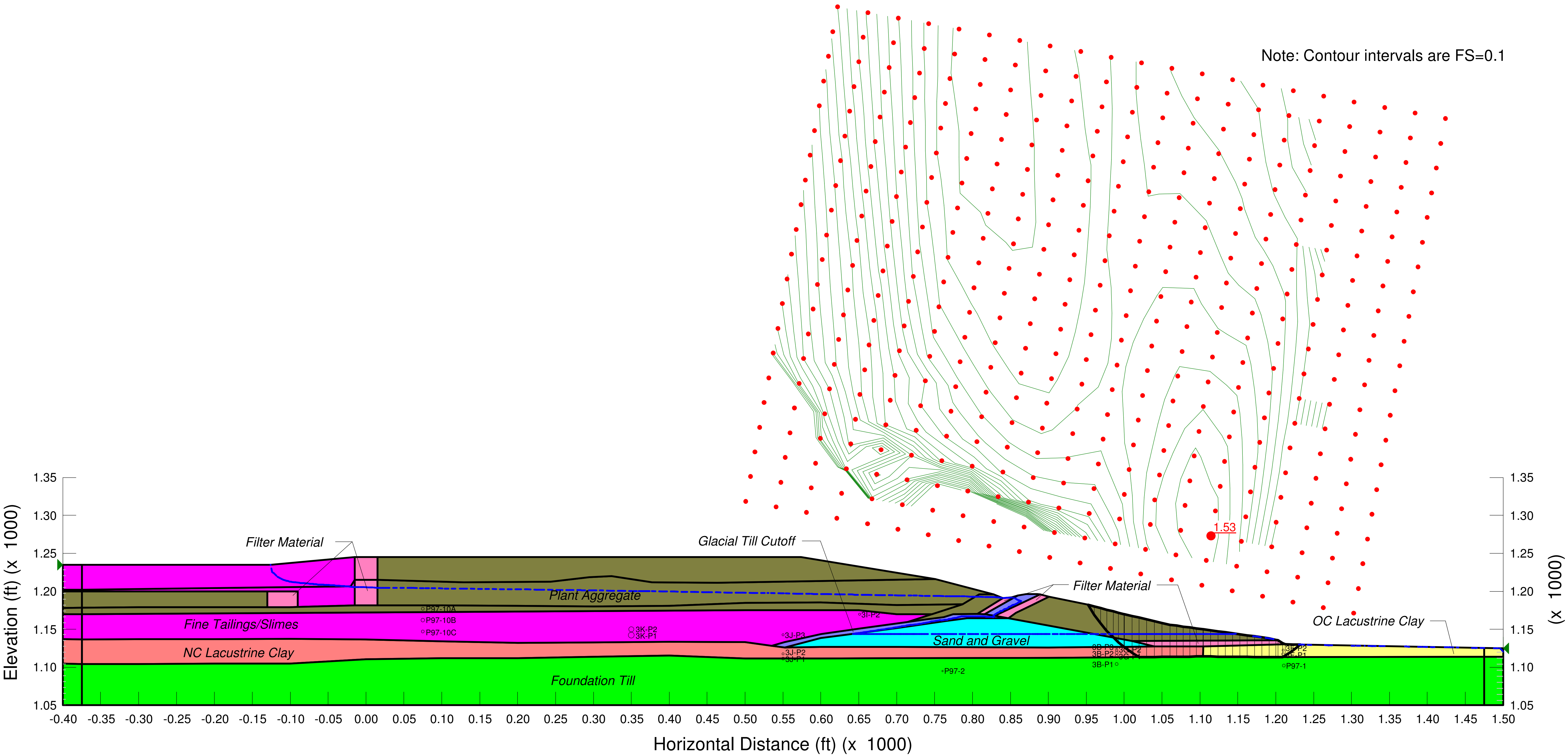
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Block
File Name: D1_S2840_E1245_ESSA_LC4_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.39



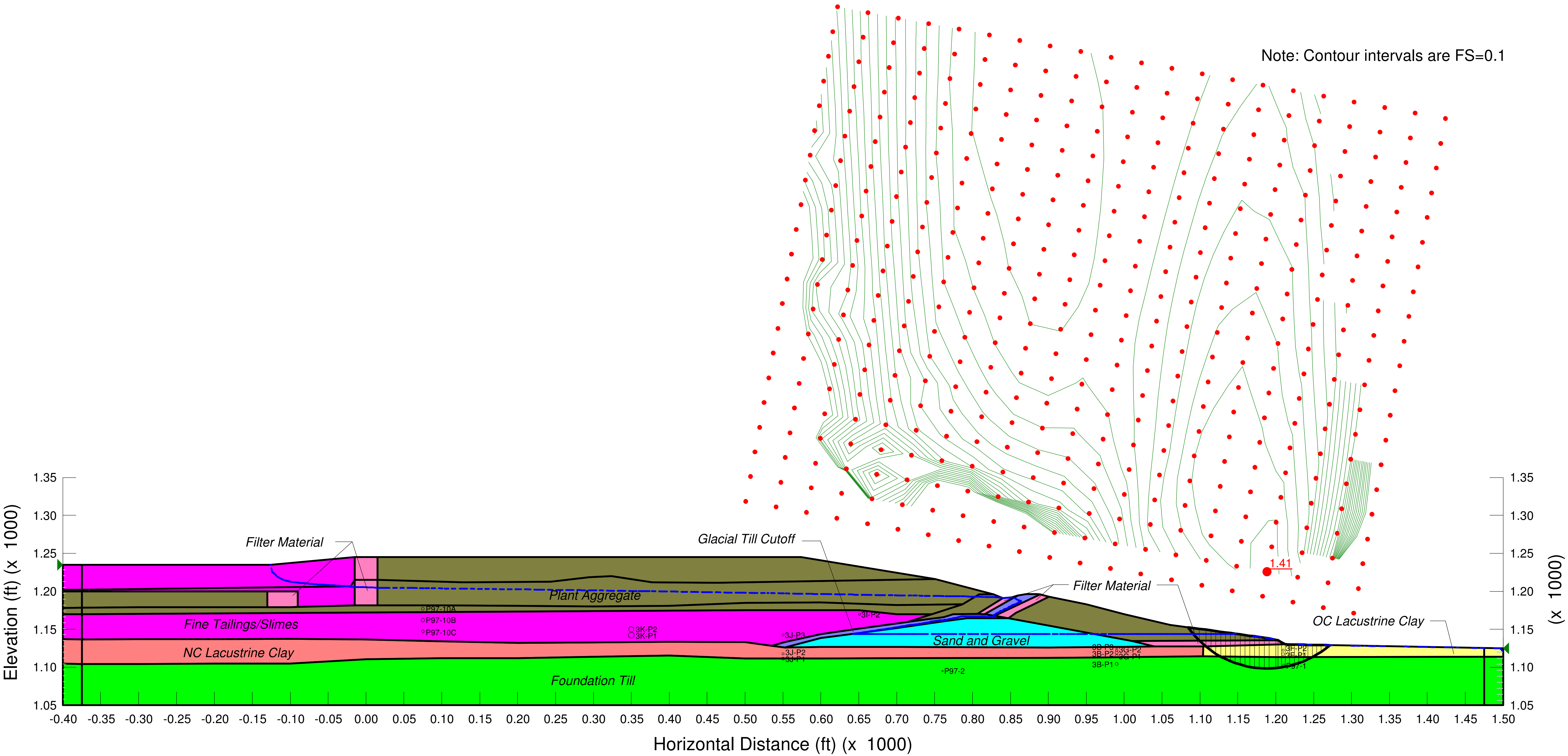
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D1_S2840_E1245_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.41



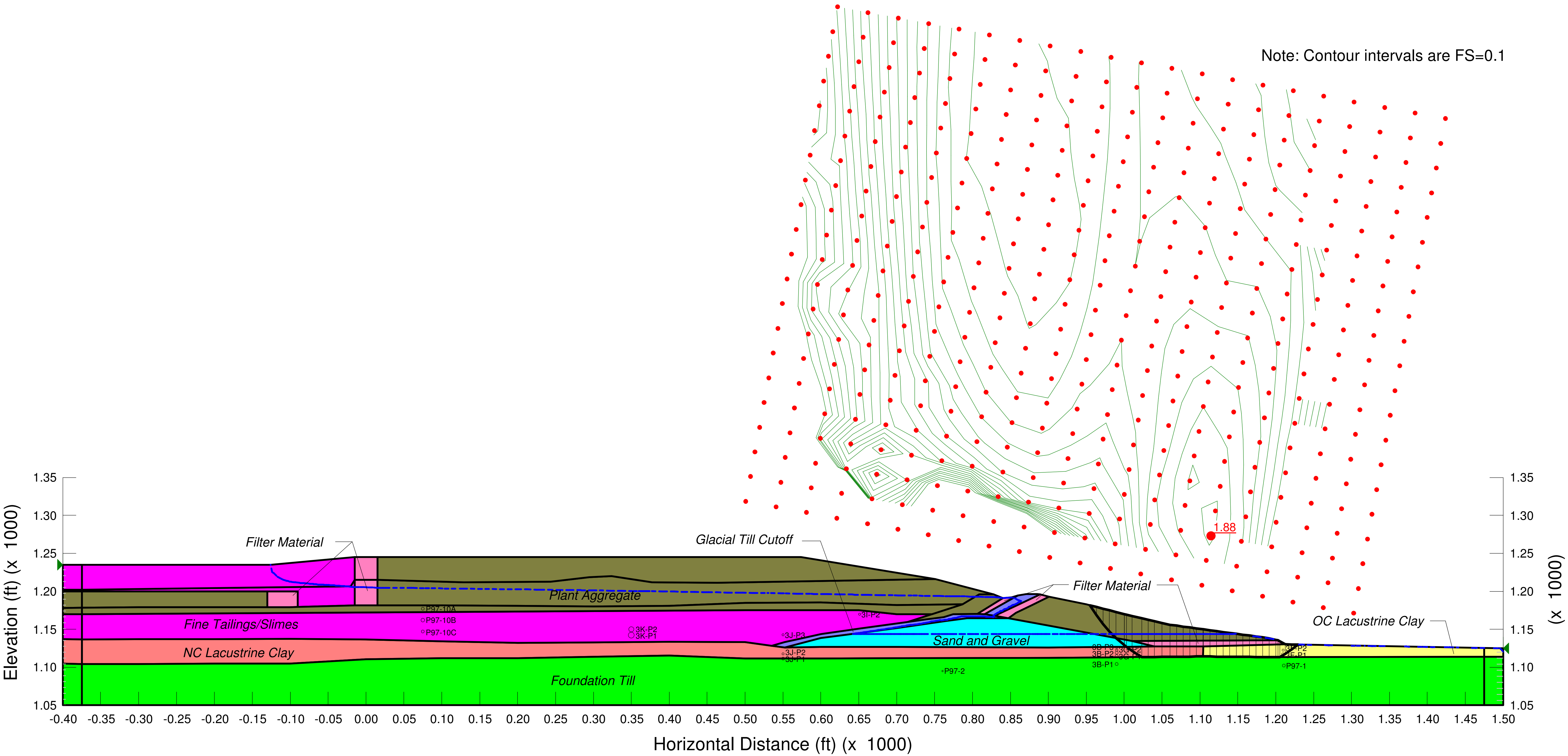
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D1_S2840_E1245_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.53



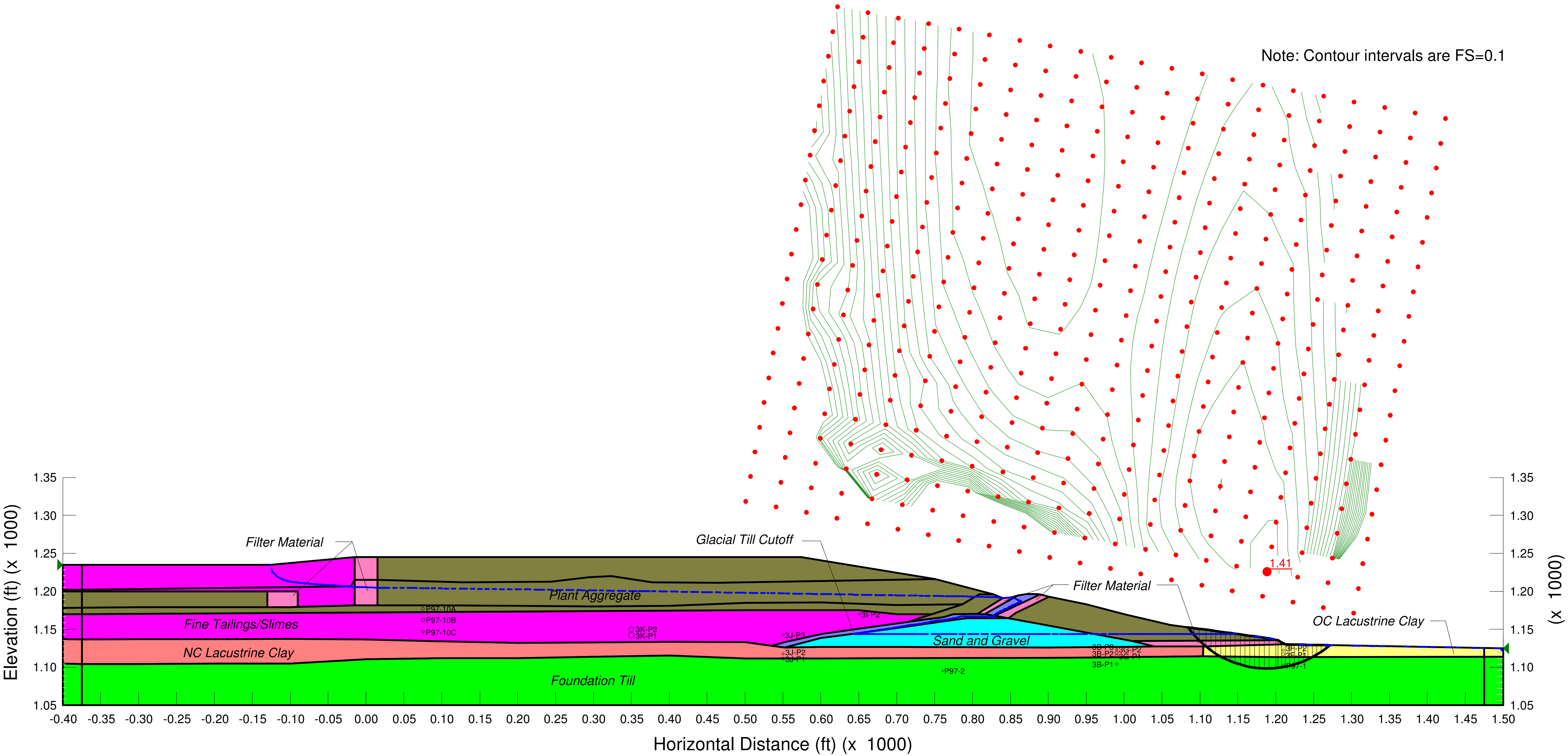
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D1_S2840_E1245_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.41



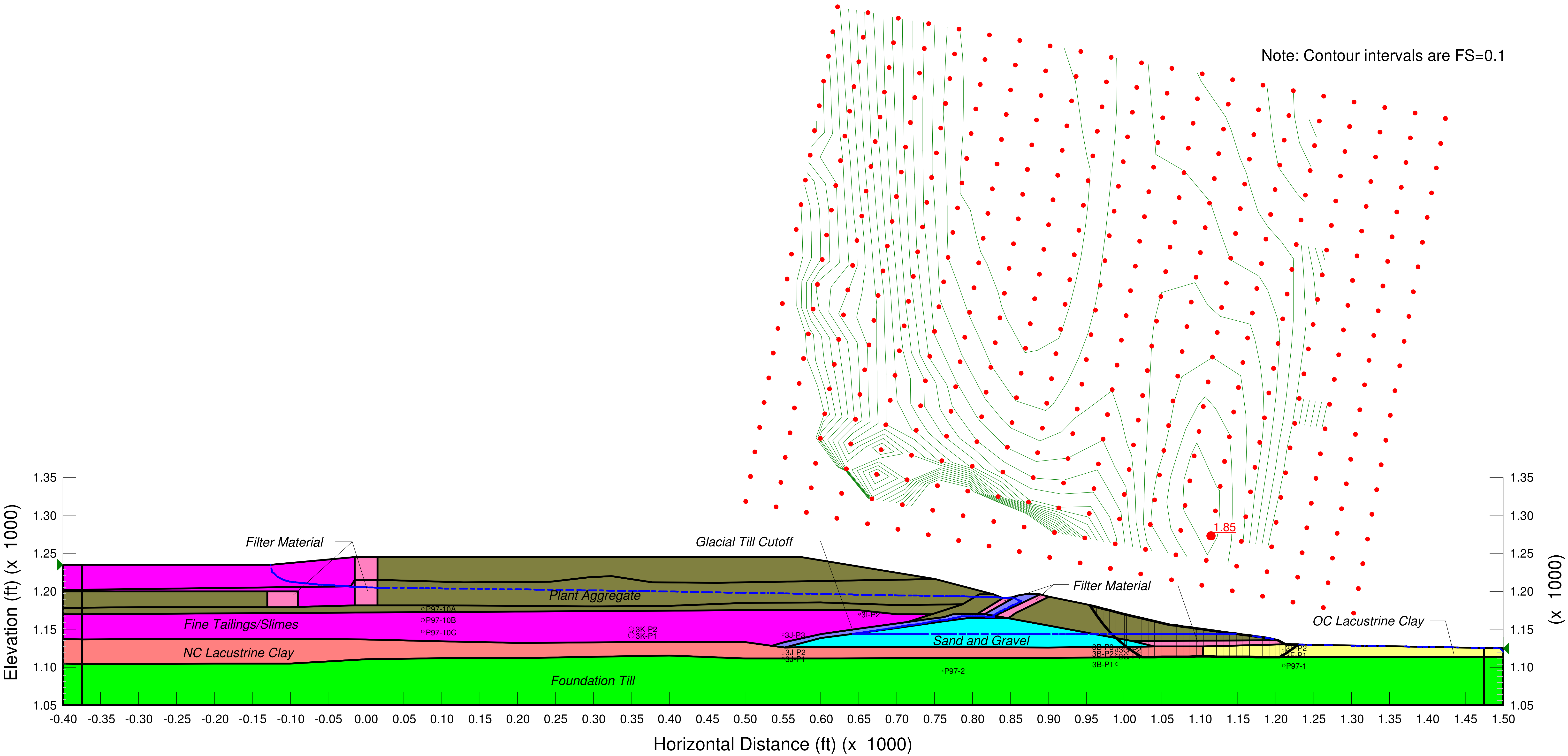
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D1_S2840_E1245_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.88



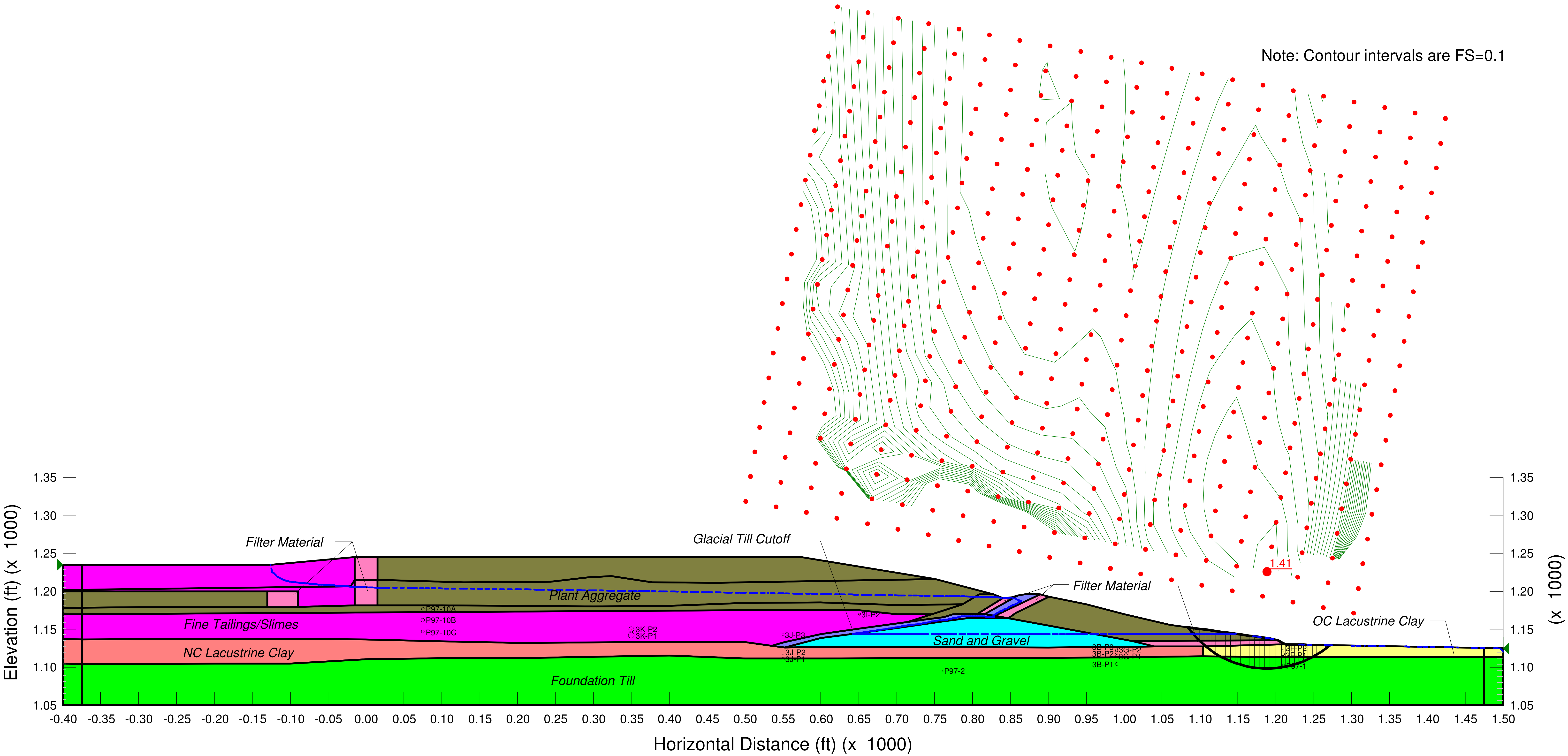
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D1_S2840_E1245_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.41



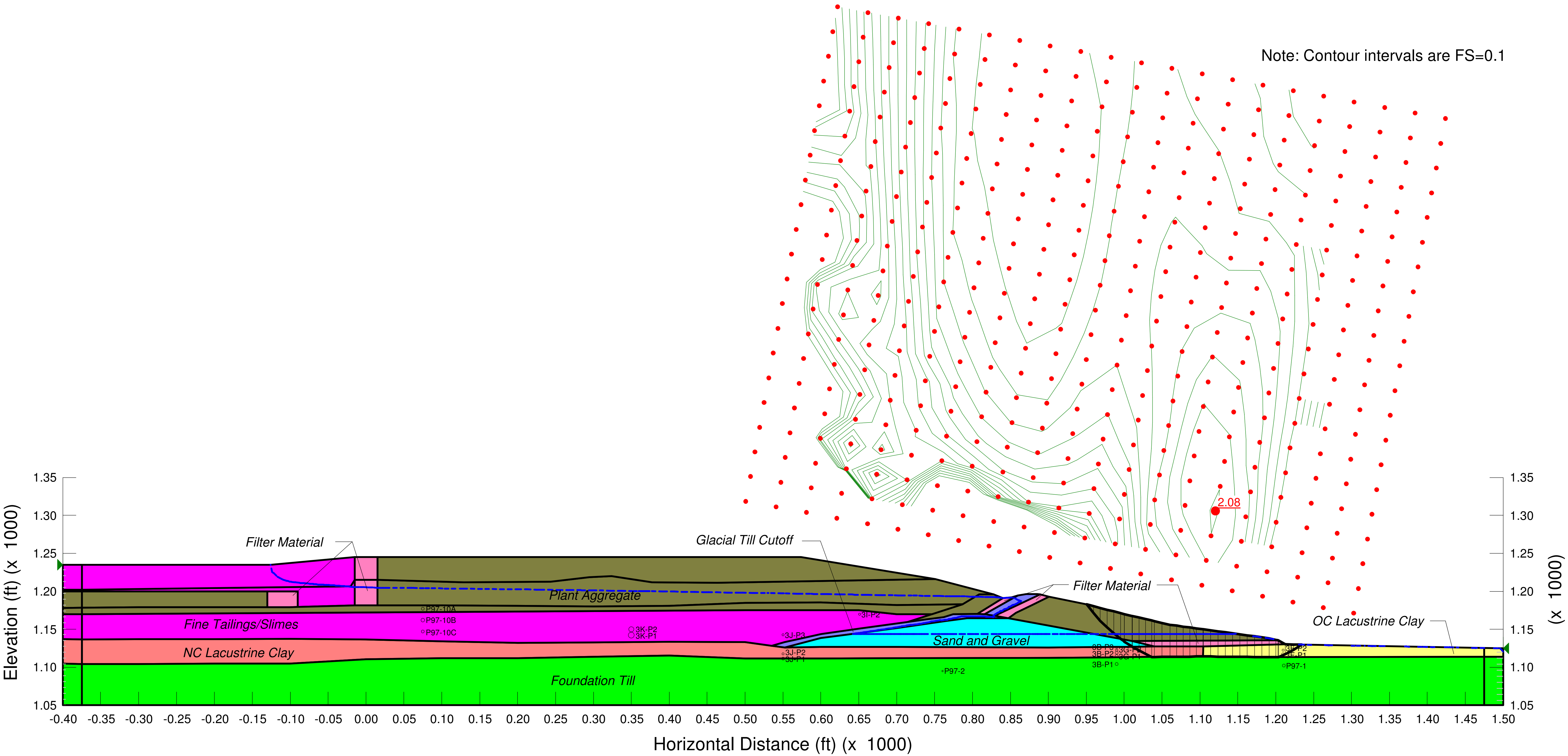
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.1, FM Block
File Name: D1_S2840_E1245_USSA_LC7_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.85



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D1_S2840_E1245_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.41

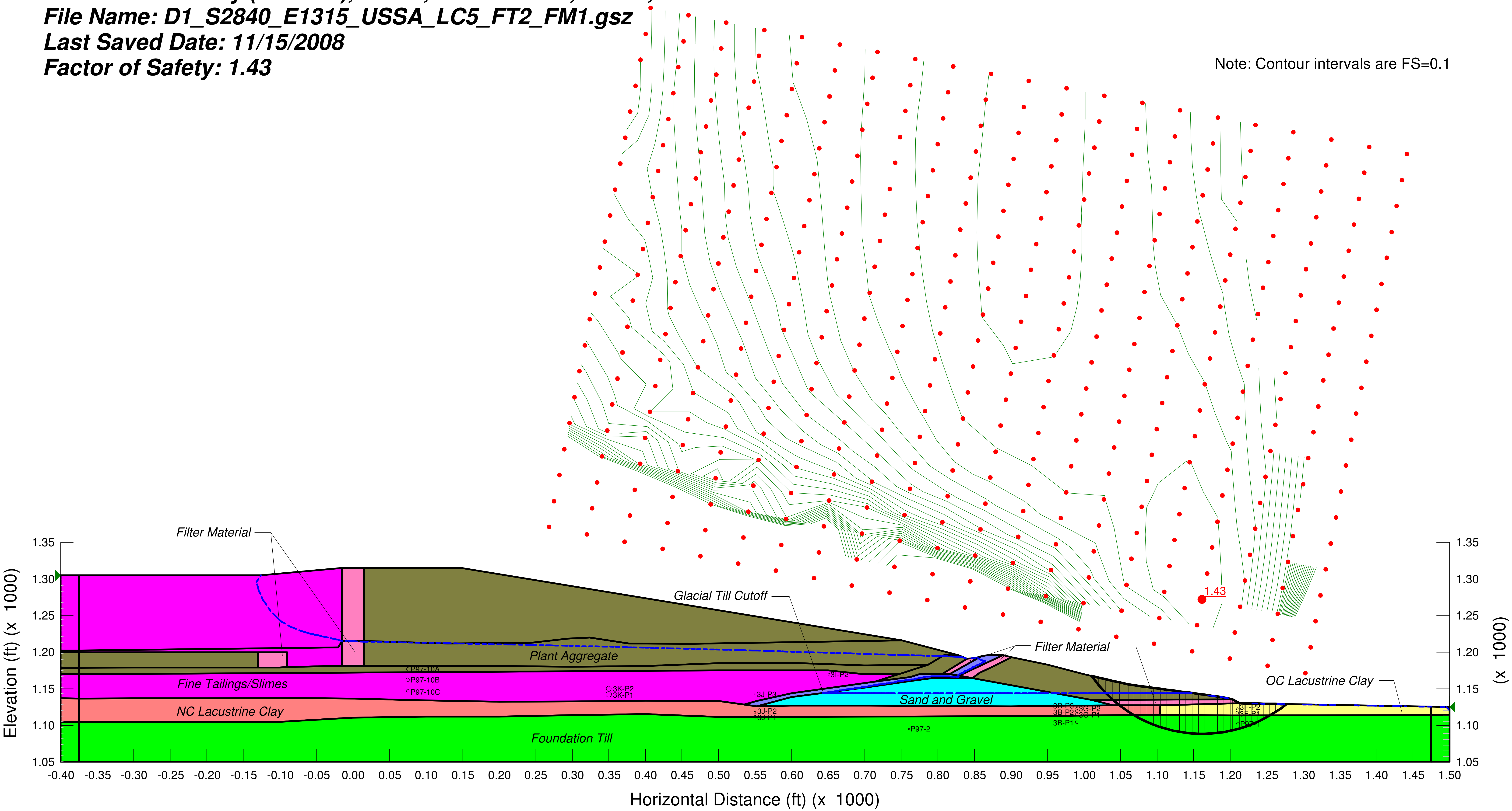


Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D1_S2840_E1245_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.08

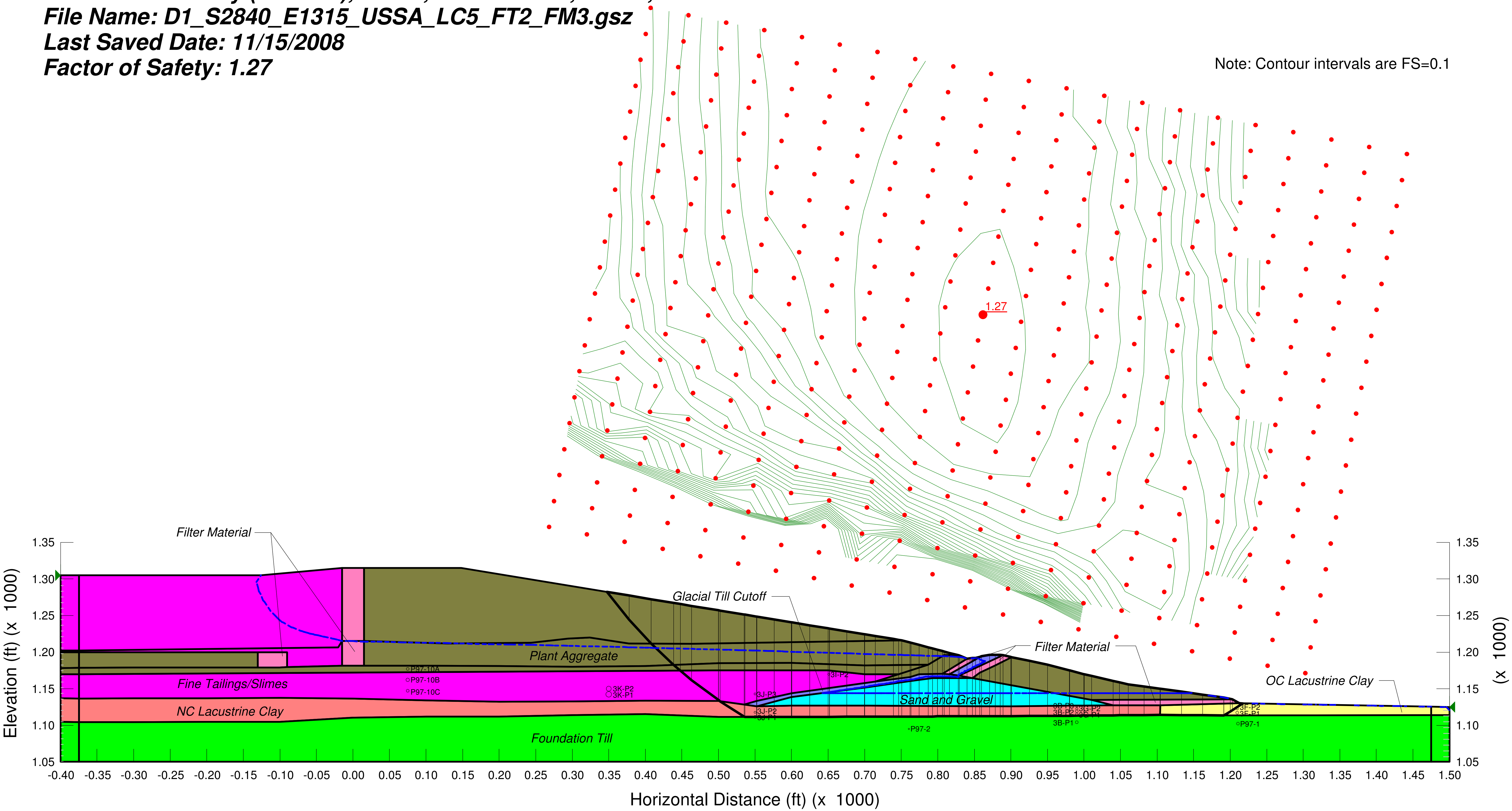


Proposed Geometry El. 1,315 feet

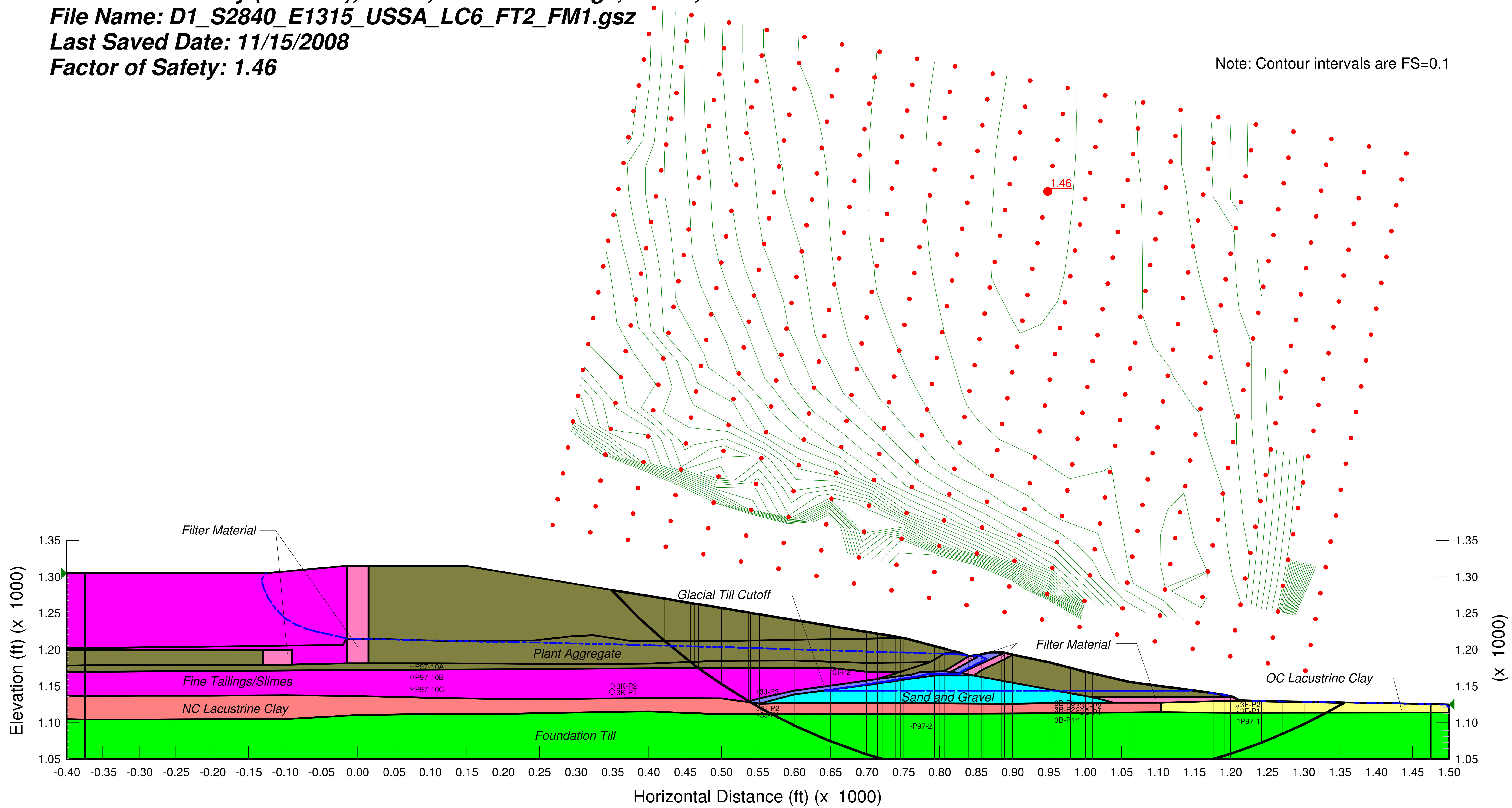
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D1_S2840_E1315_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.43



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D1_S2840_E1315_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.27



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D1_S2840_E1315_USSA_LC6_FT2_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.46



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.2, FM Block
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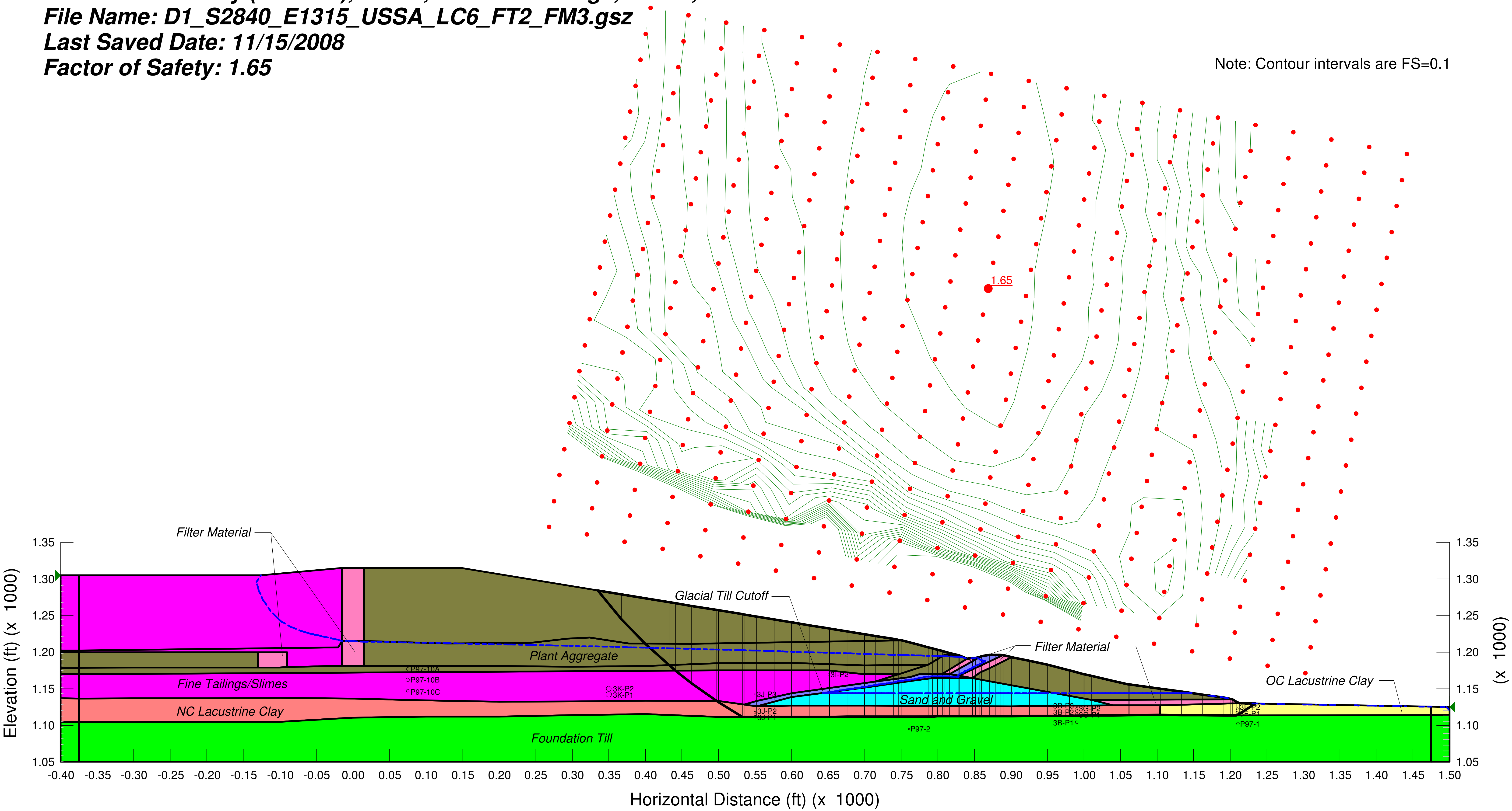
Last Saved Date: 11/15/2008
Factor of Safety: 1.65



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.2, FM Toe
File Name: D1_S2840_E1315_USSA_LC7_FT2_FM1.gsz
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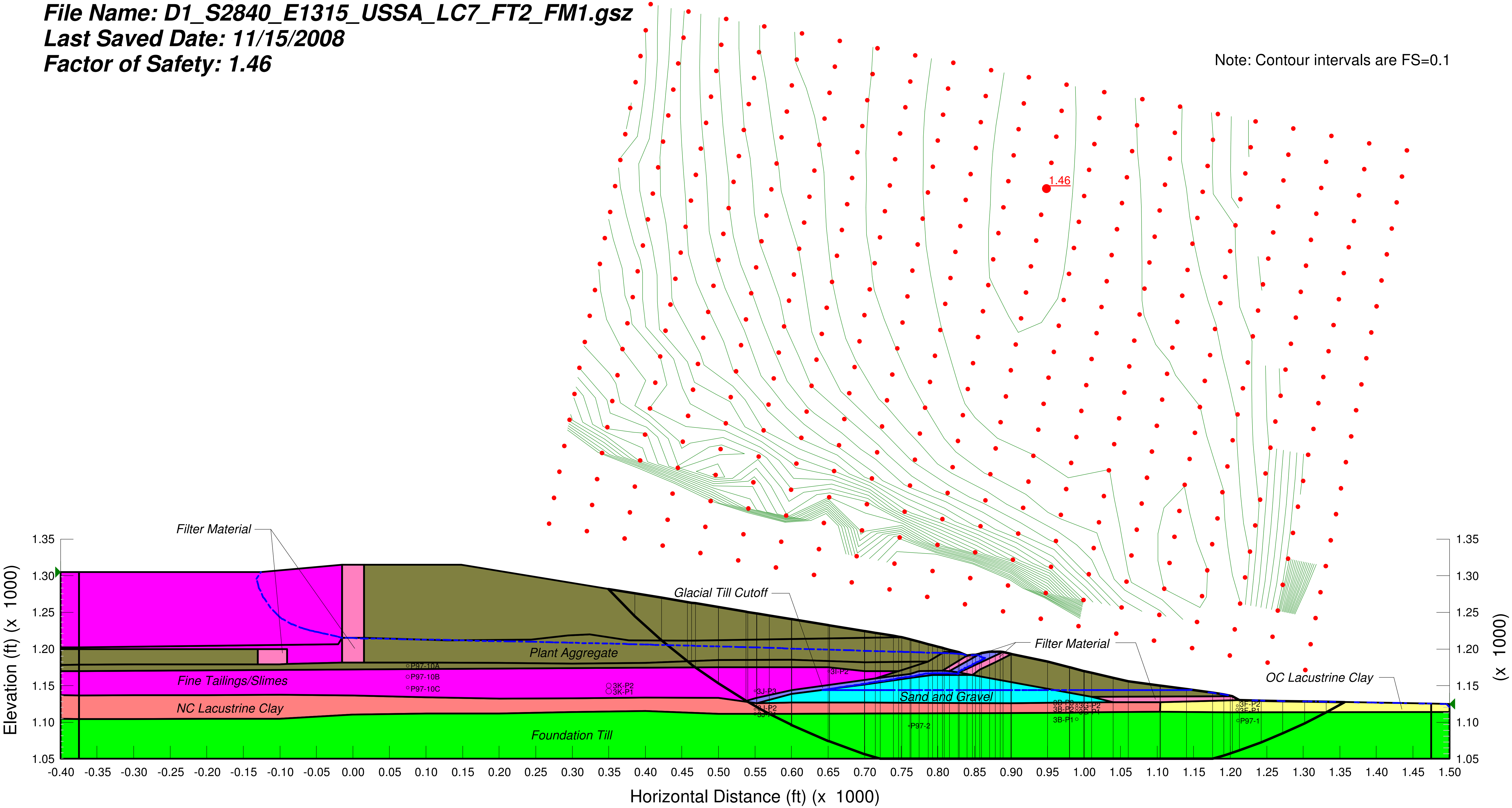
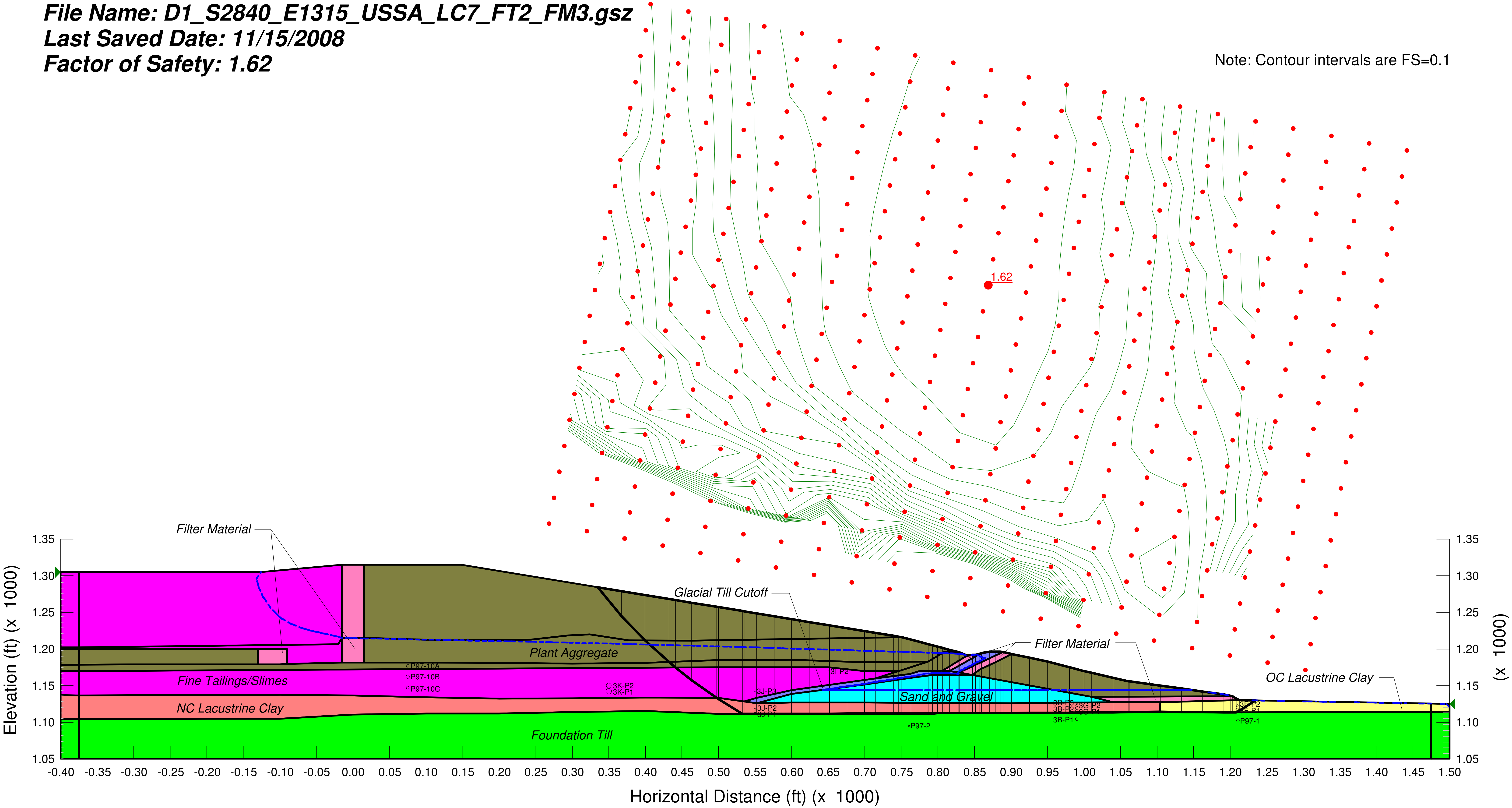
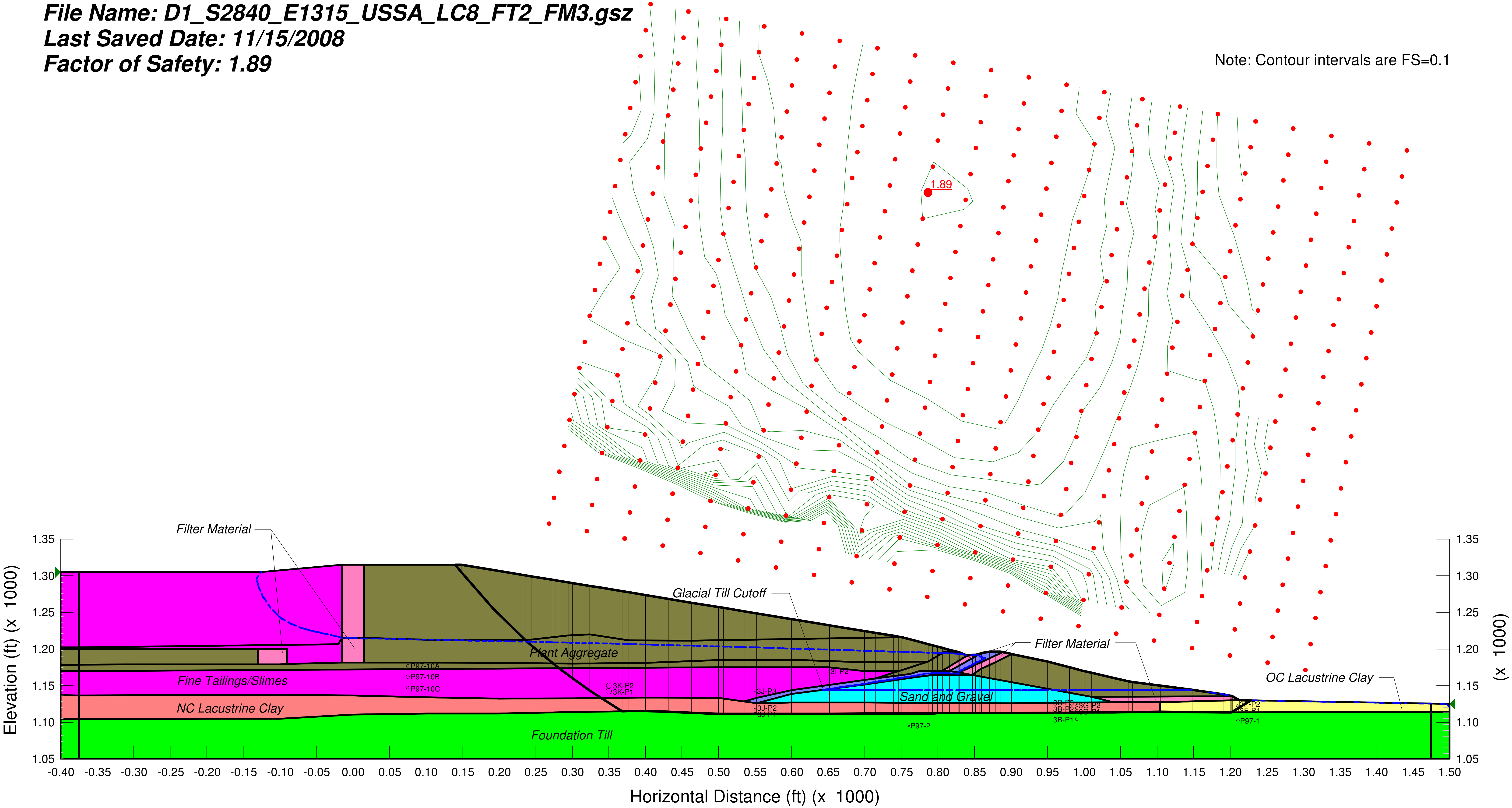
Factor of Safety: 1.46



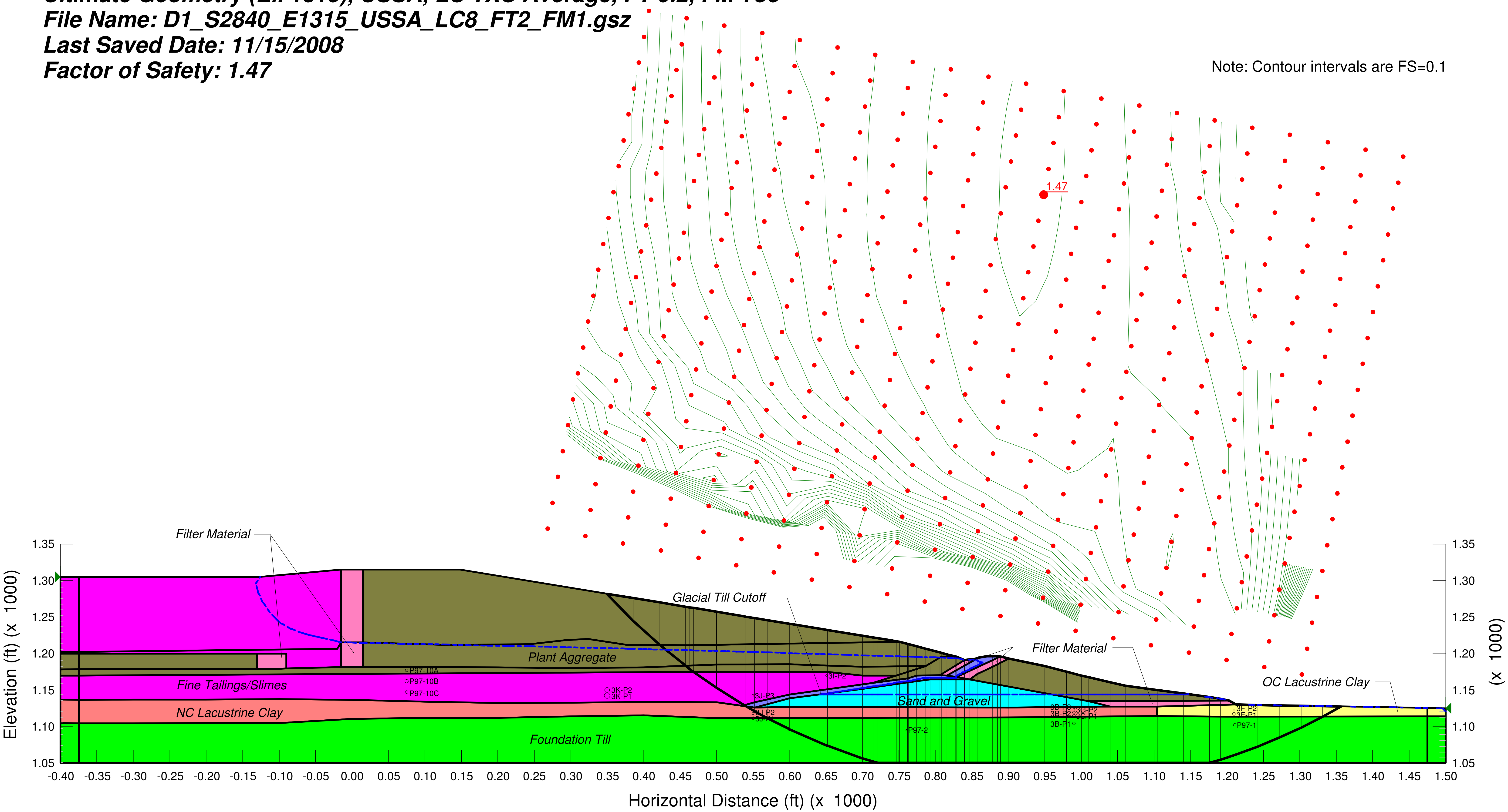
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.2, FM Block
File Name: D1_S2840_E1315_USSA_LC7_FT2_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.62



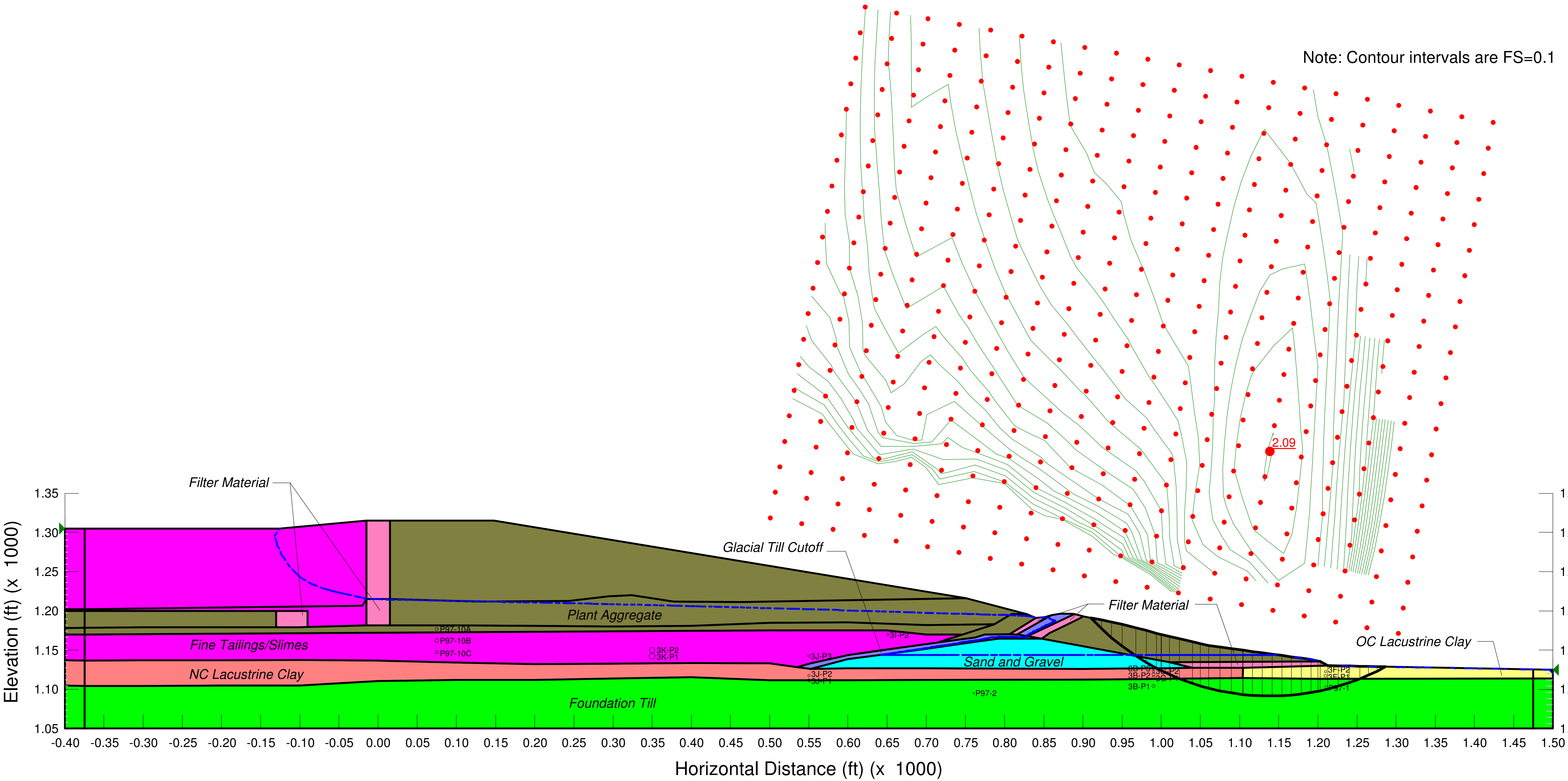
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D1_S2840_E1315_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.89



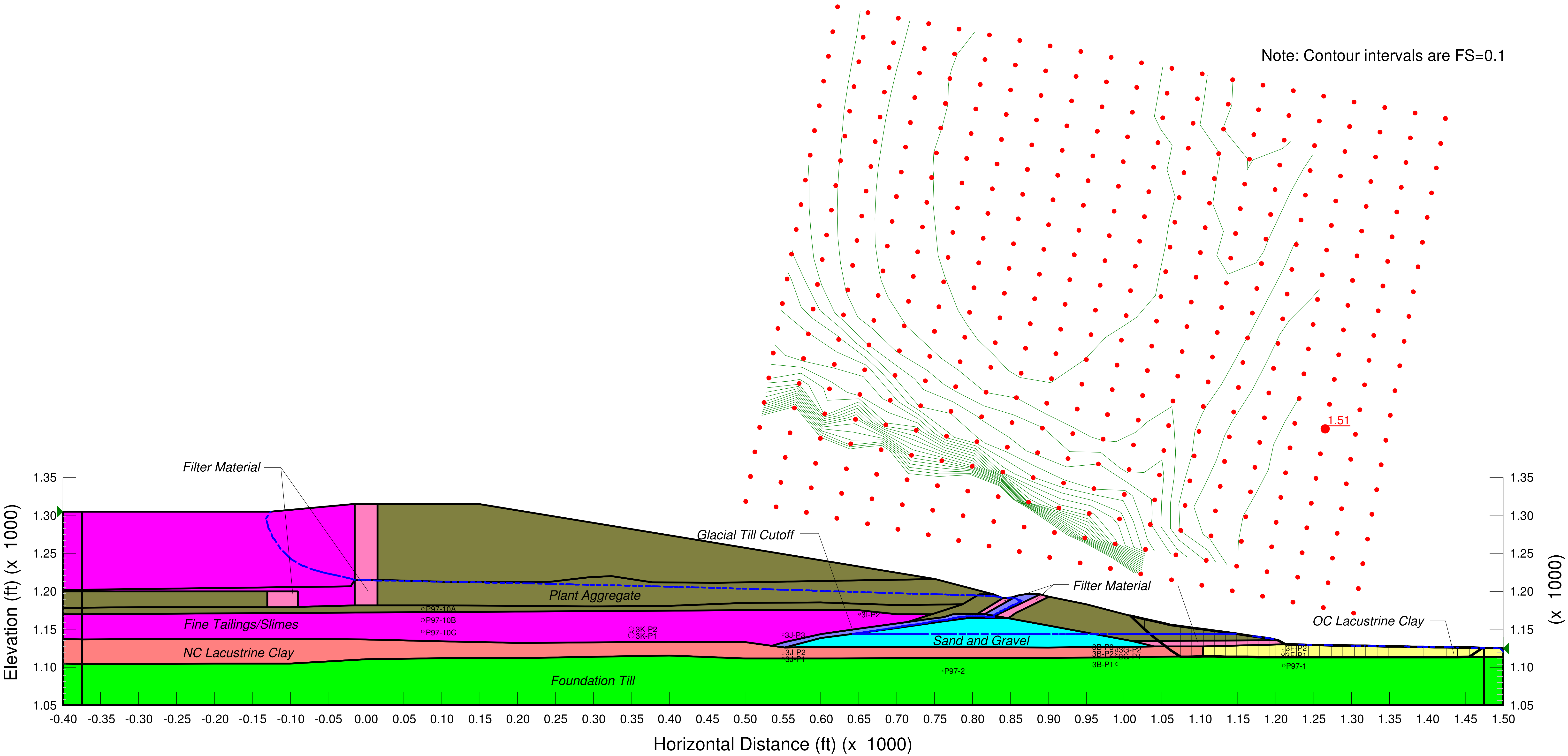
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D1_S2840_E1315_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.47



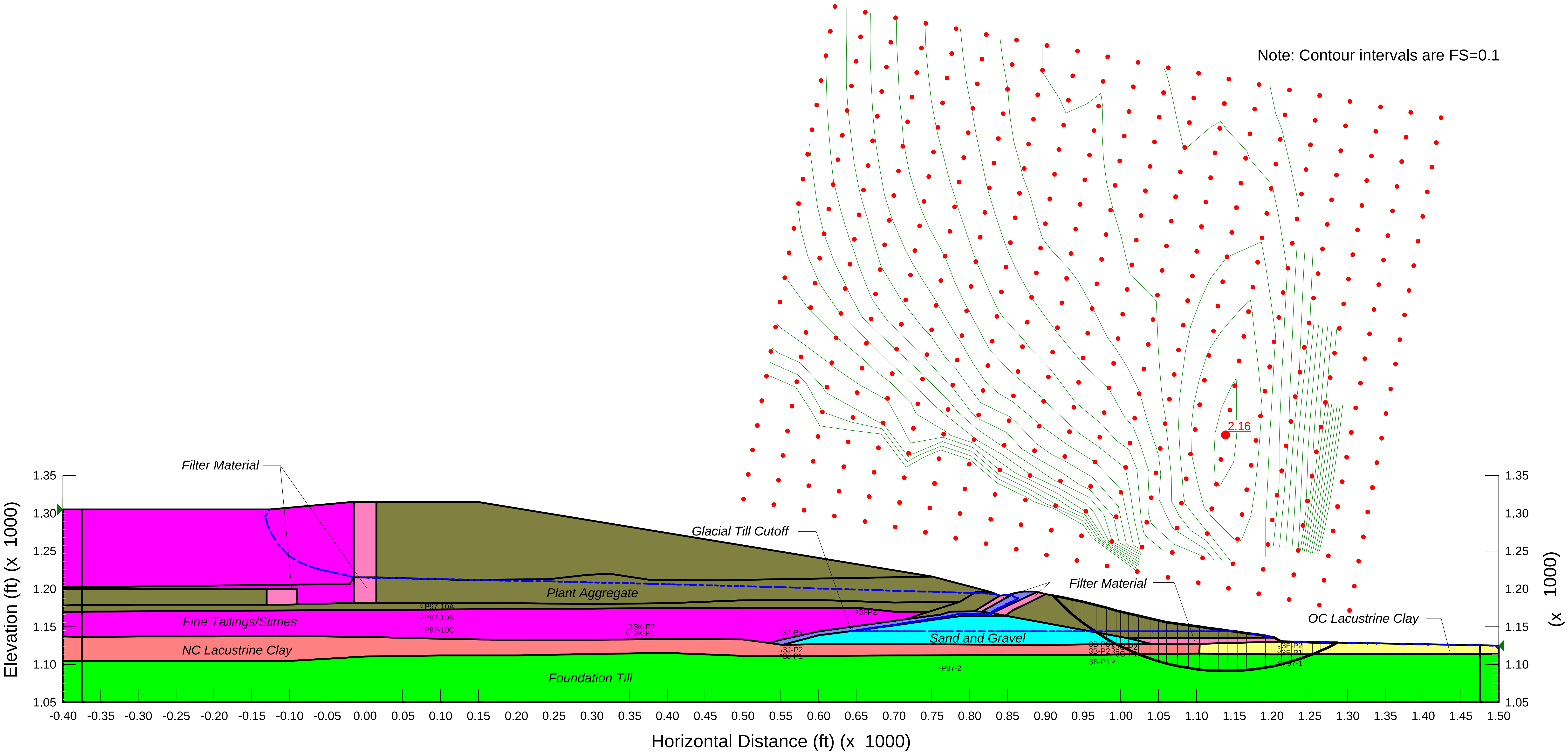
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Low, FM Toe
File Name: D1_S2840_E1315_ESSA_LC1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.09



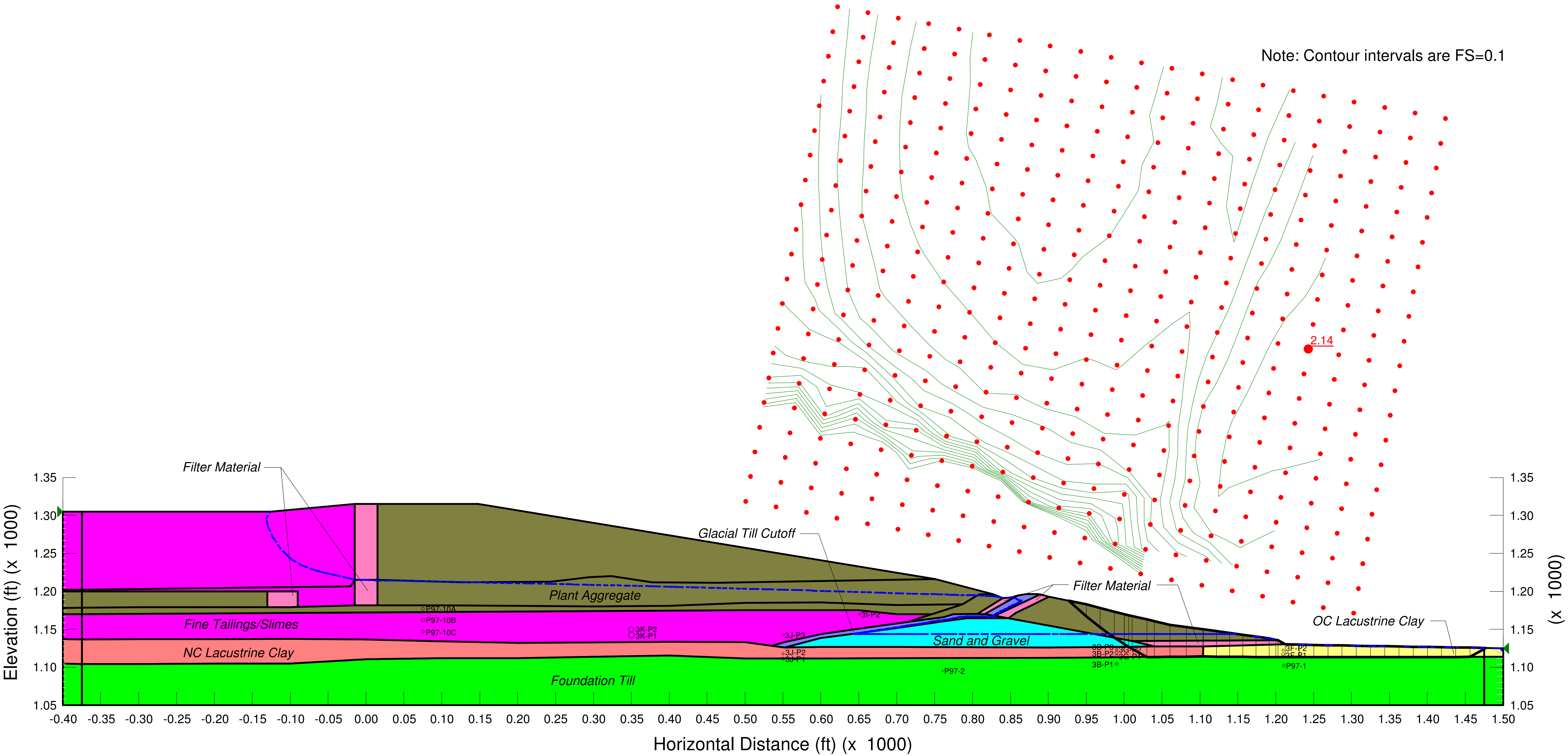
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Low, FM Block
File Name: D1_S2840_E1315_ESSA_LC1_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.51



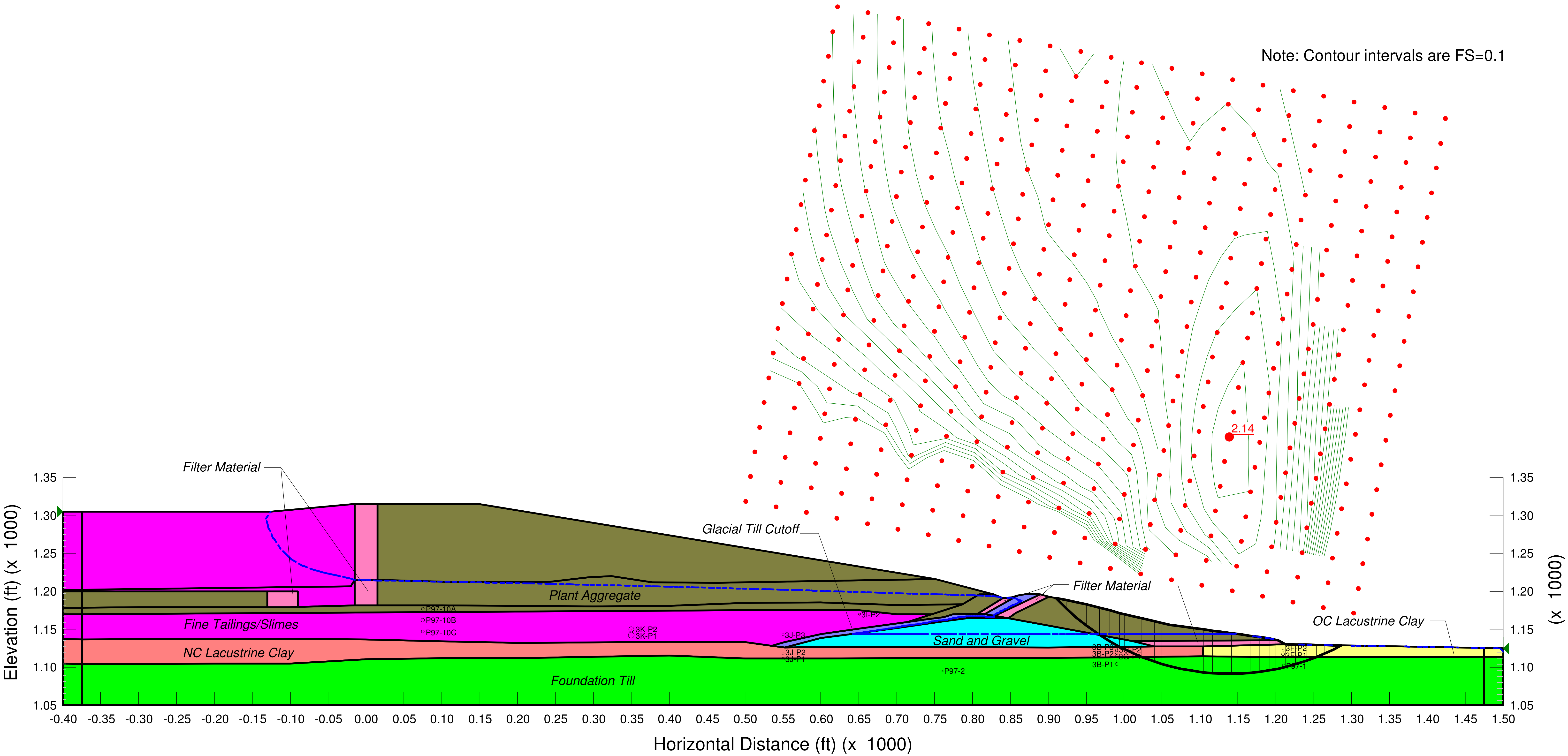
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Toe
File Name: D1_S2840_E1315_ESSA_LC2_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.16



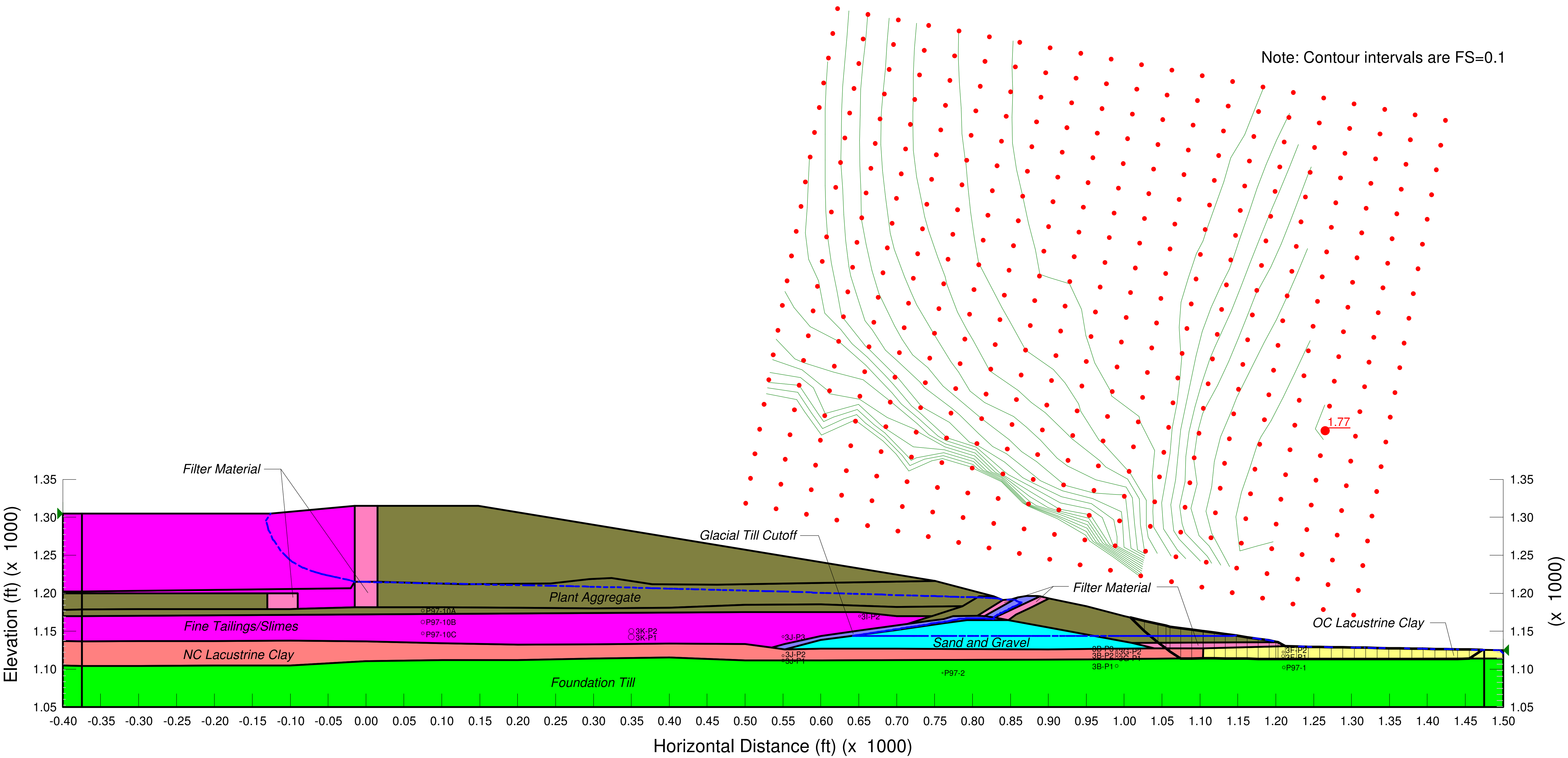
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Block
File Name: D1_S2840_E1315_ESSA_LC2_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.14



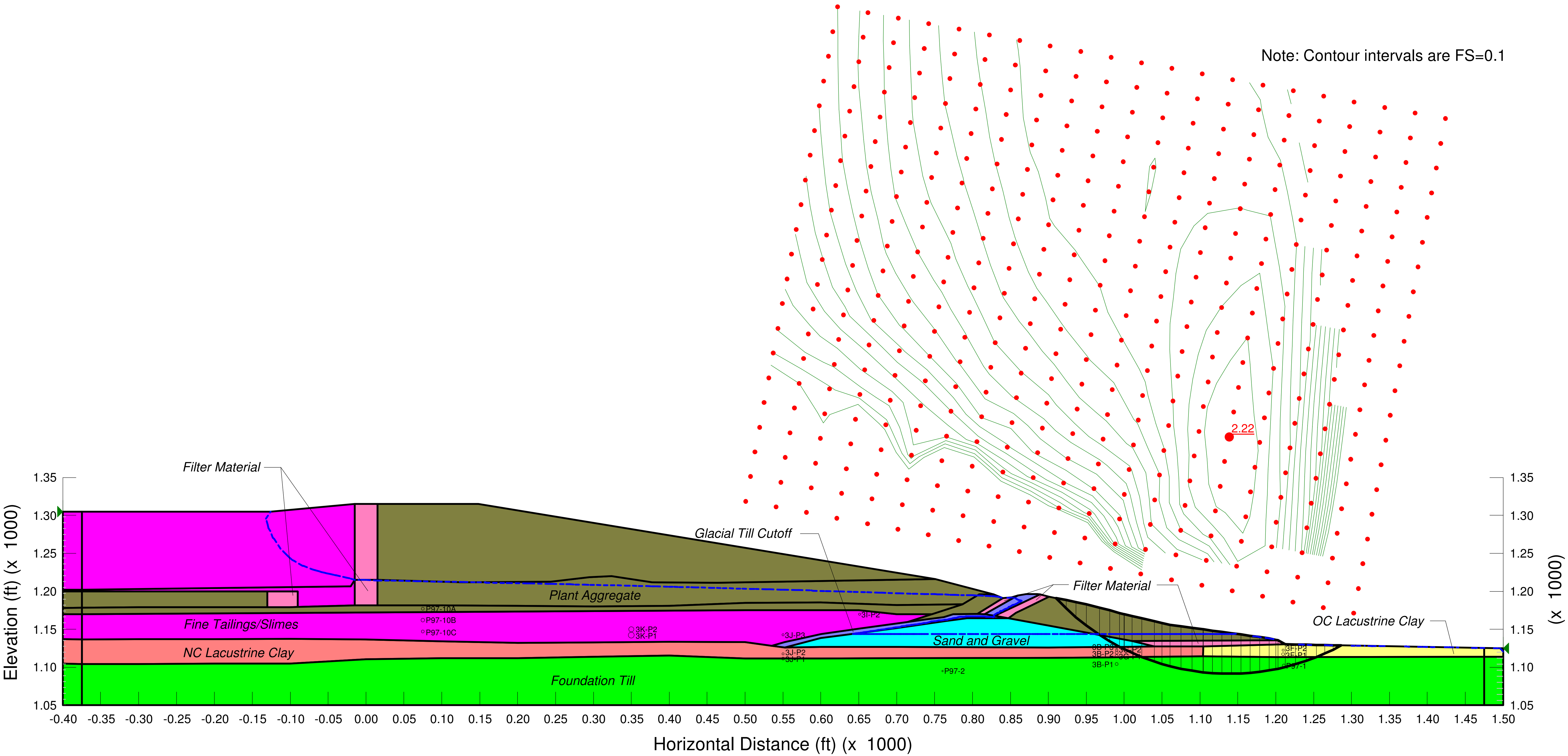
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Low, FM Toe
File Name: D1_S2840_E1315_ESSA_LC3_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.14



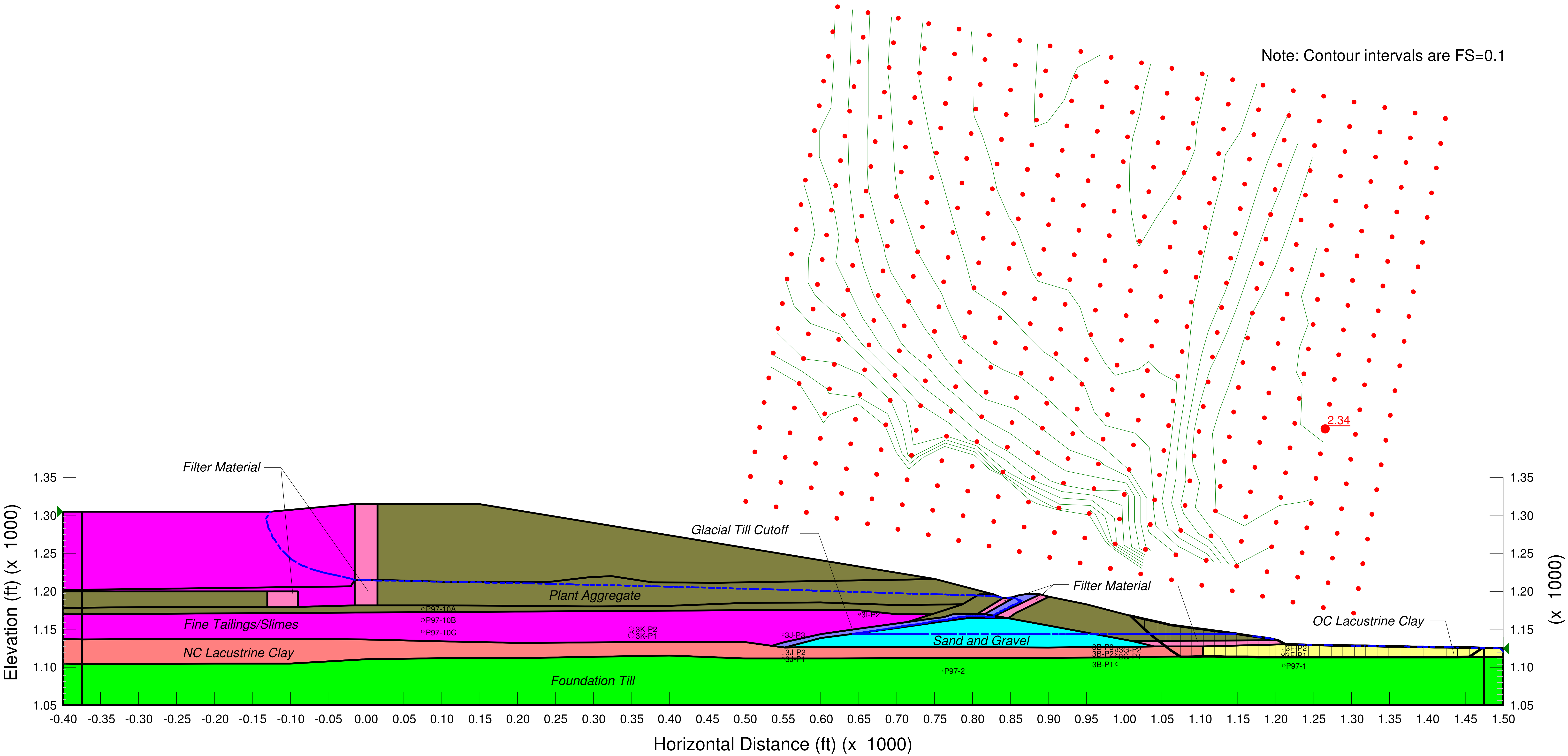
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Low, FM Block
File Name: D1_S2840_E1315_ESSA_LC3_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.77



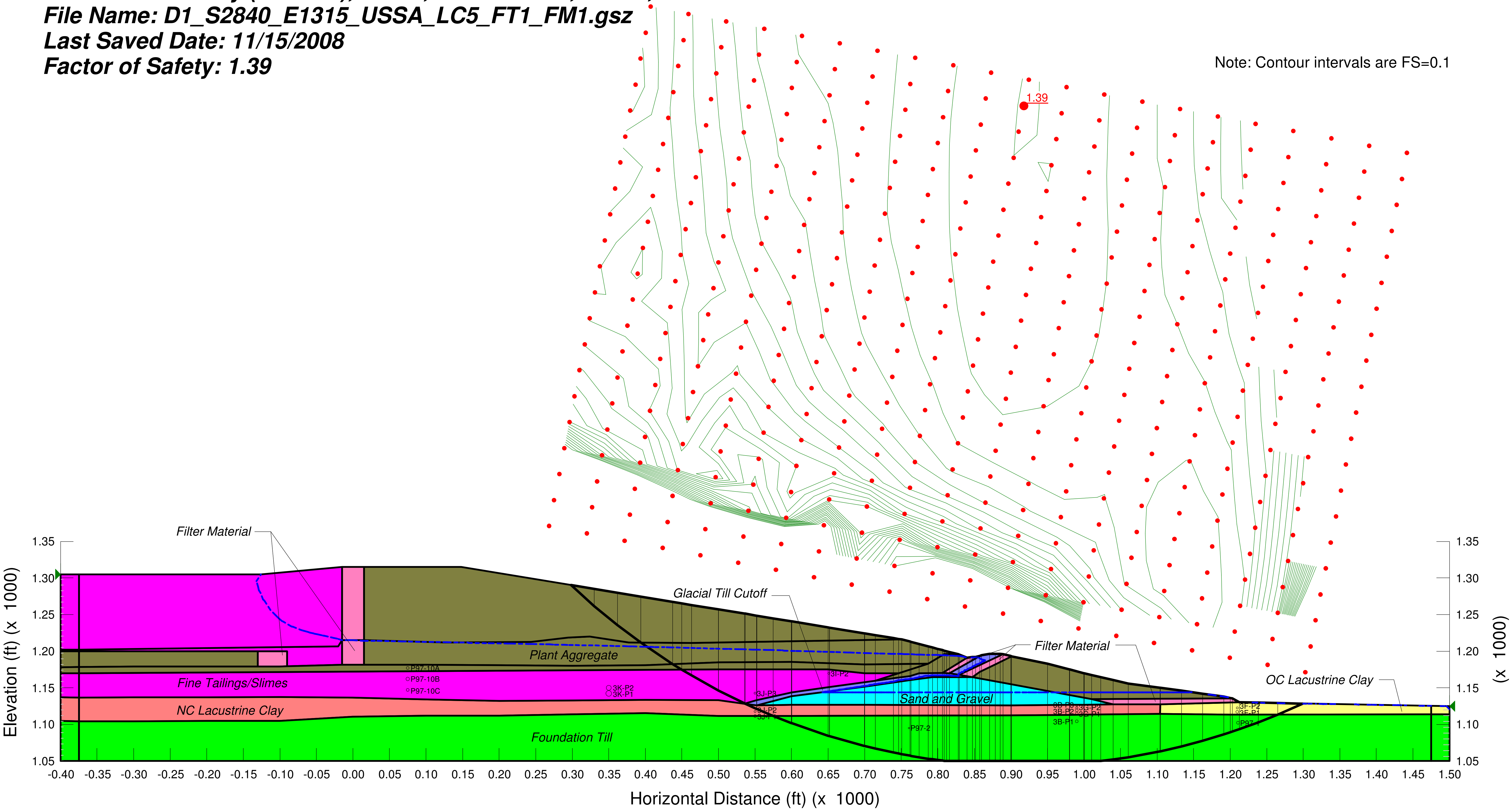
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Toe
File Name: D1_S2840_E1315_ESSA_LC4_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.22



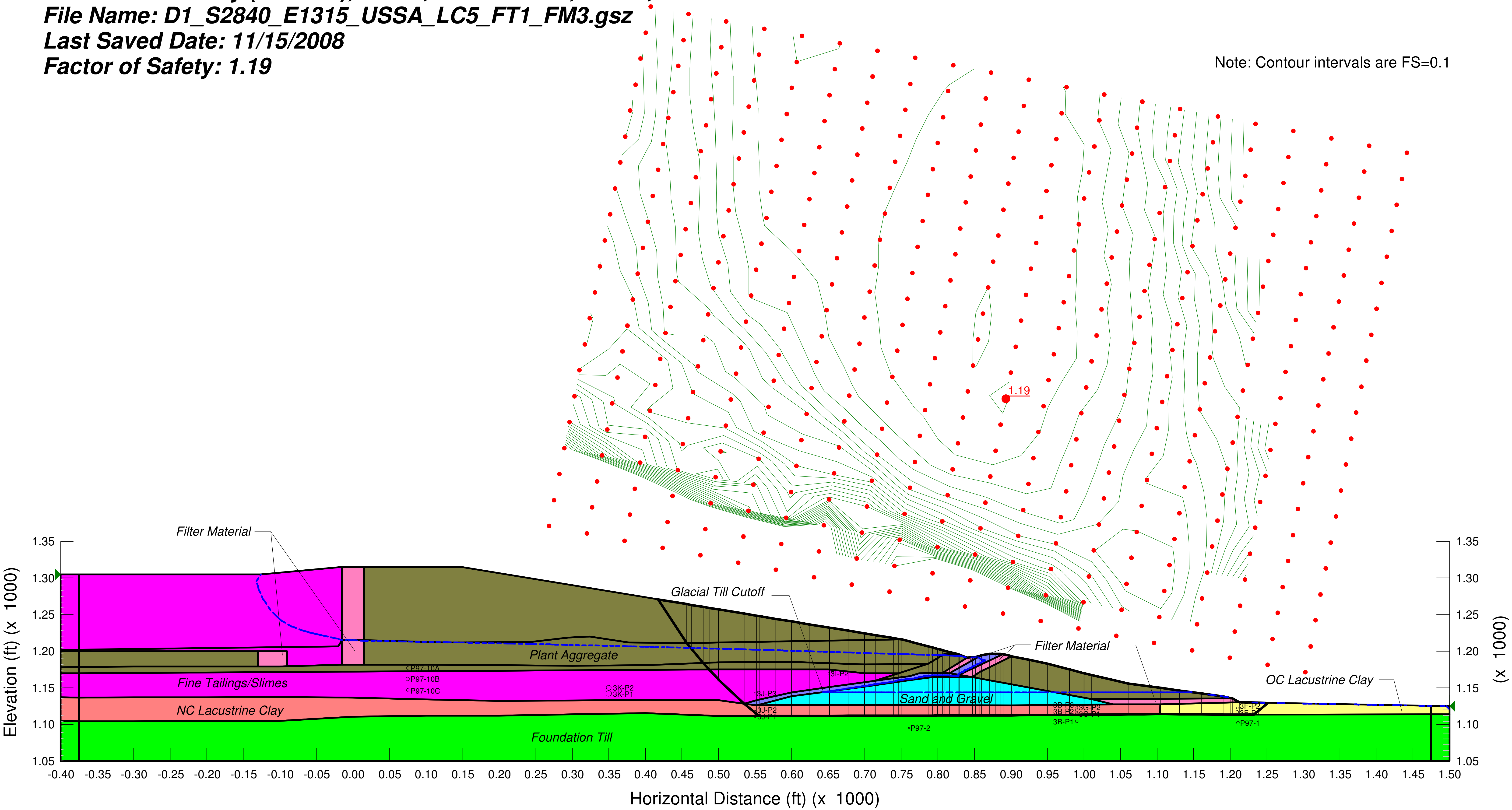
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Block
File Name: D1_S2840_E1315_ESSA_LC4_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.34



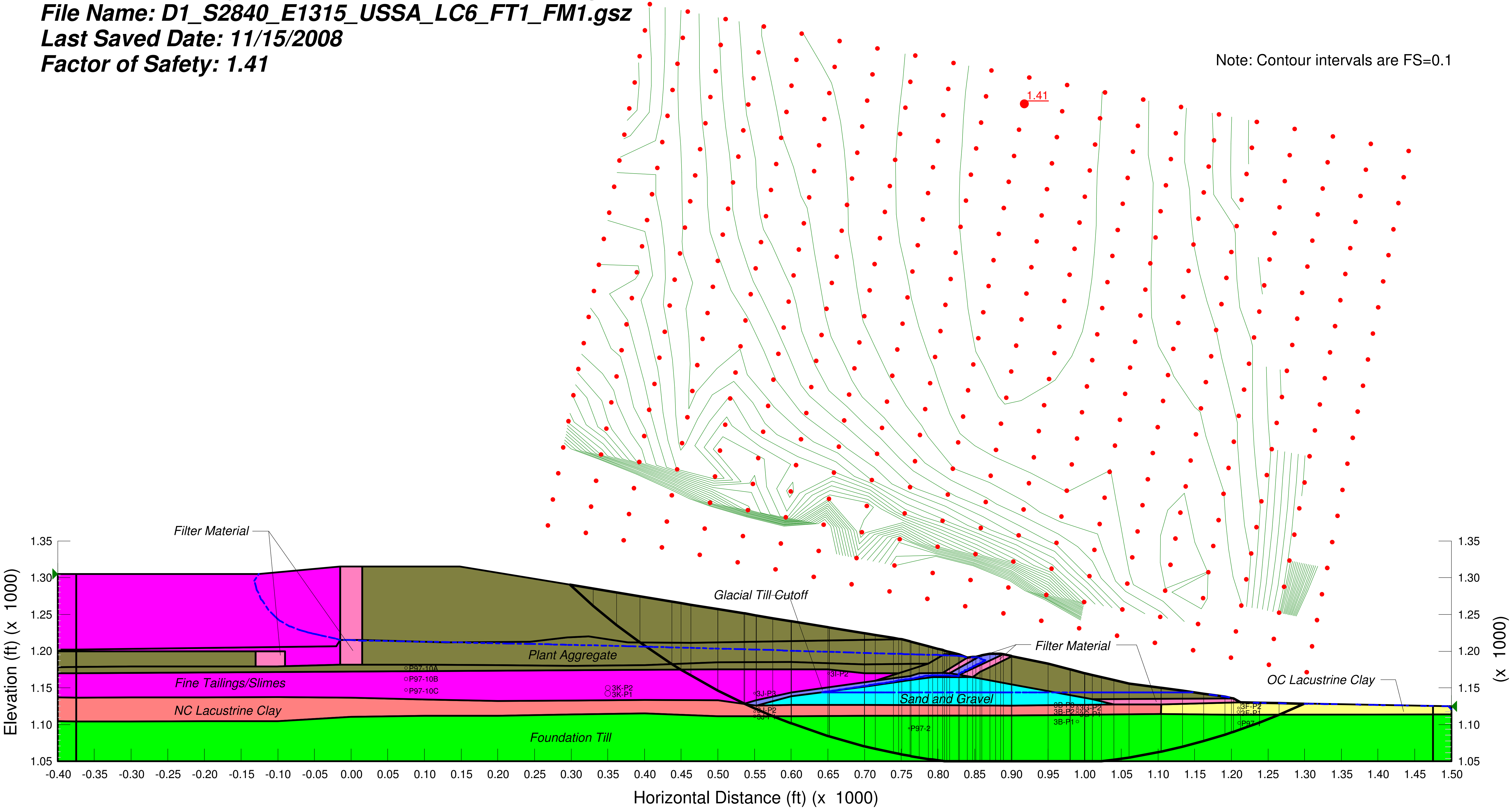
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D1_S2840_E1315_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.39



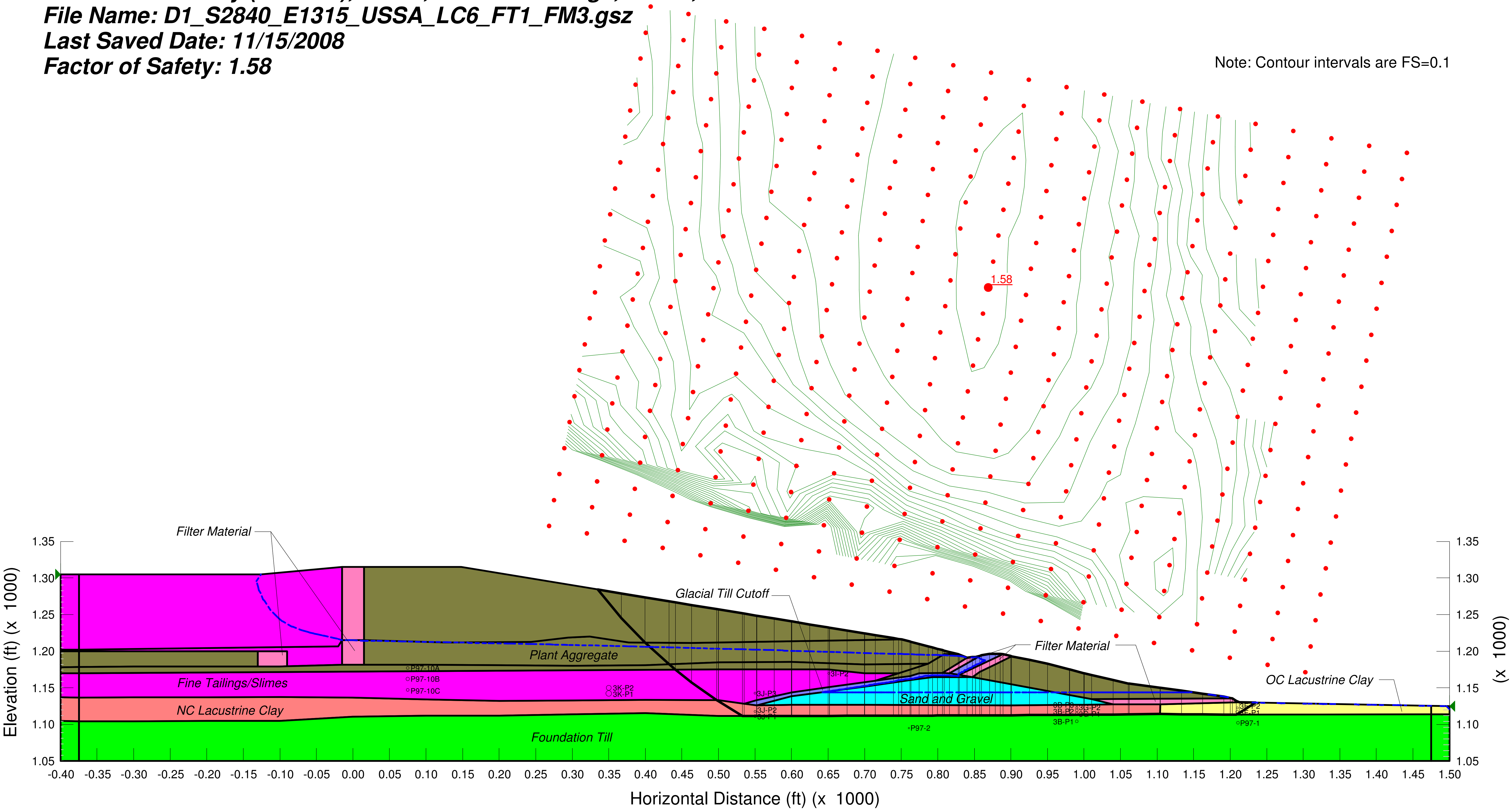
Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D1_S2840_E1315_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.19

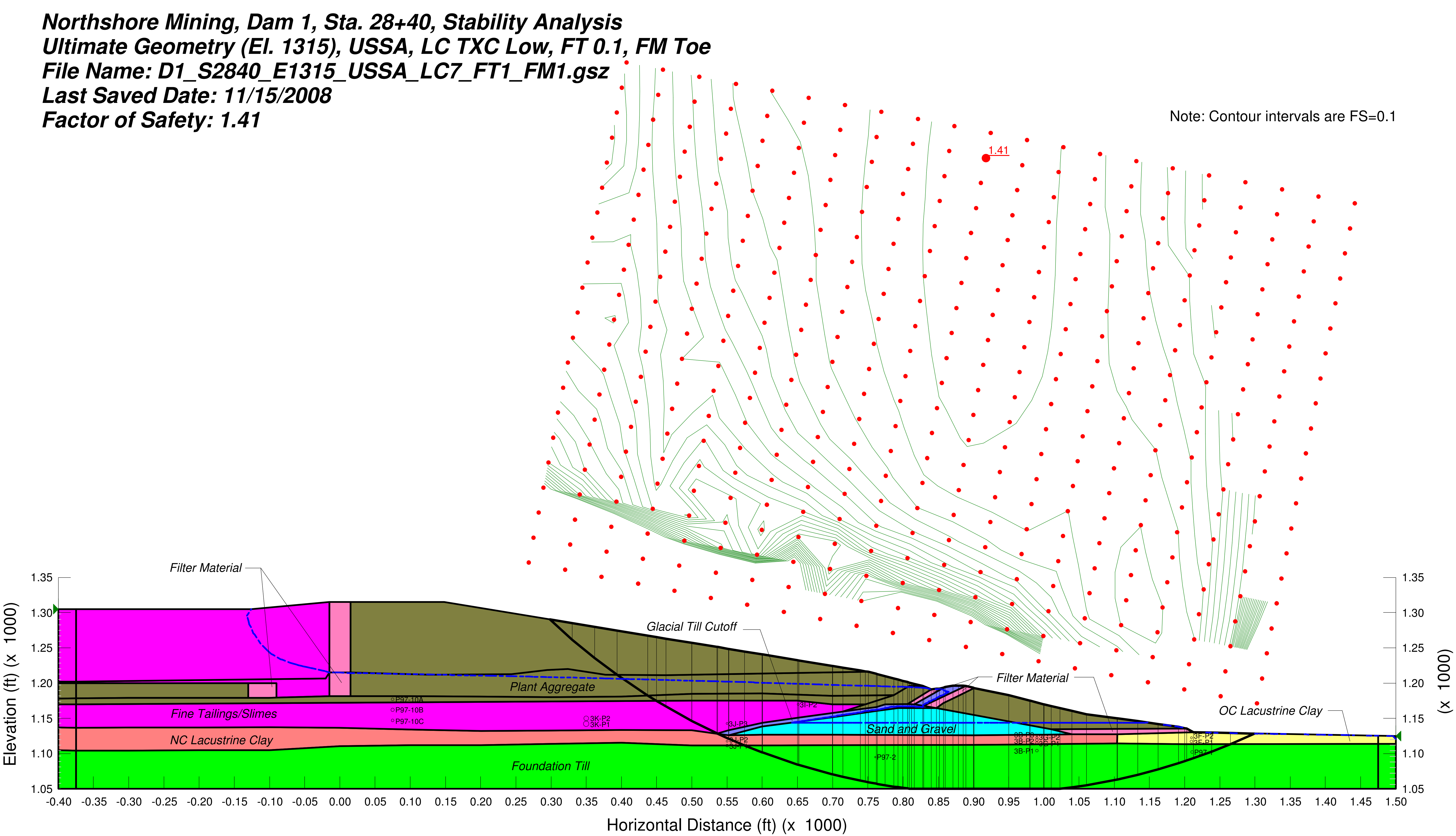


Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D1_S2840_E1315_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.41

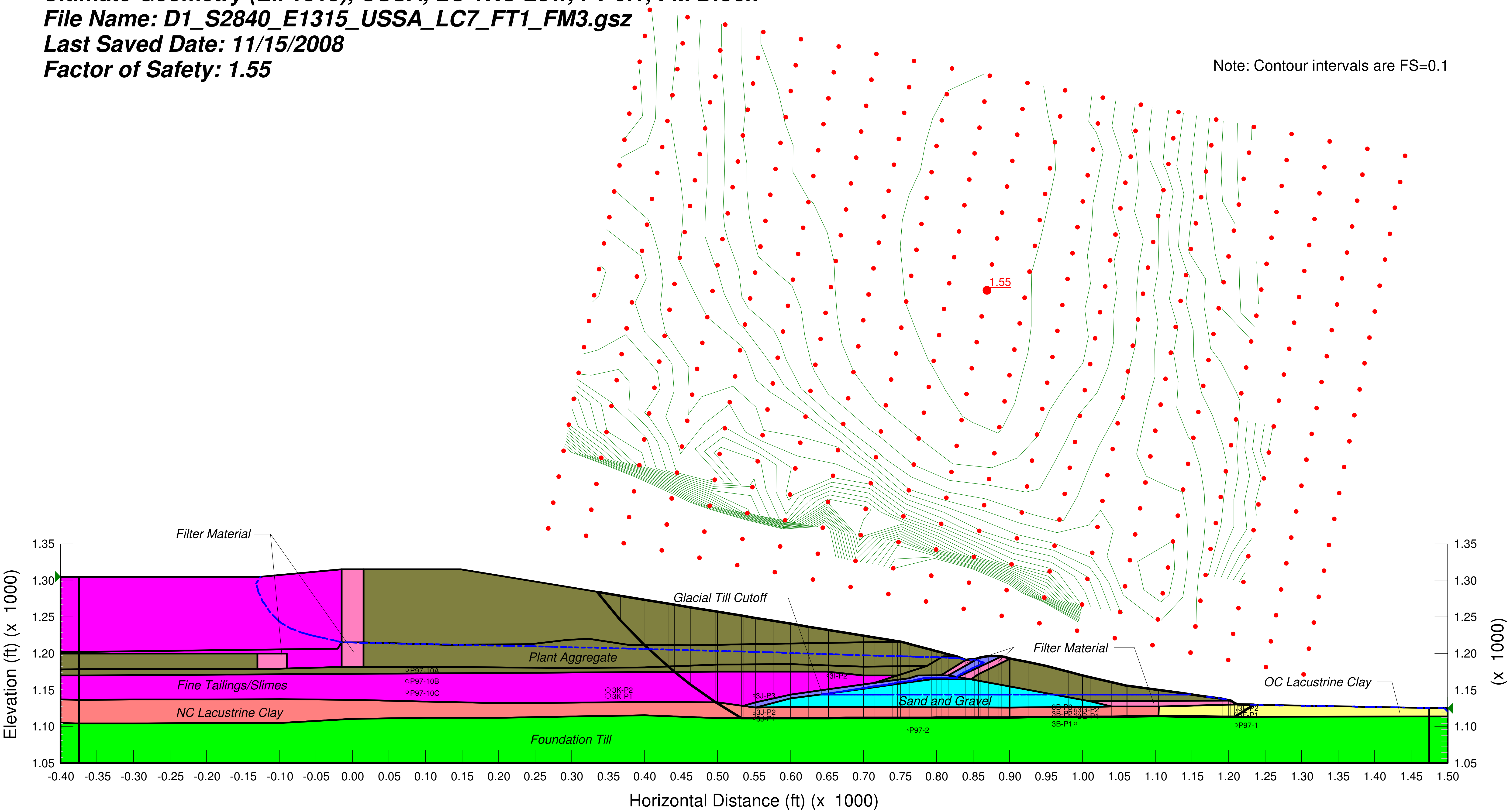


Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D1_S2840_E1315_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.58

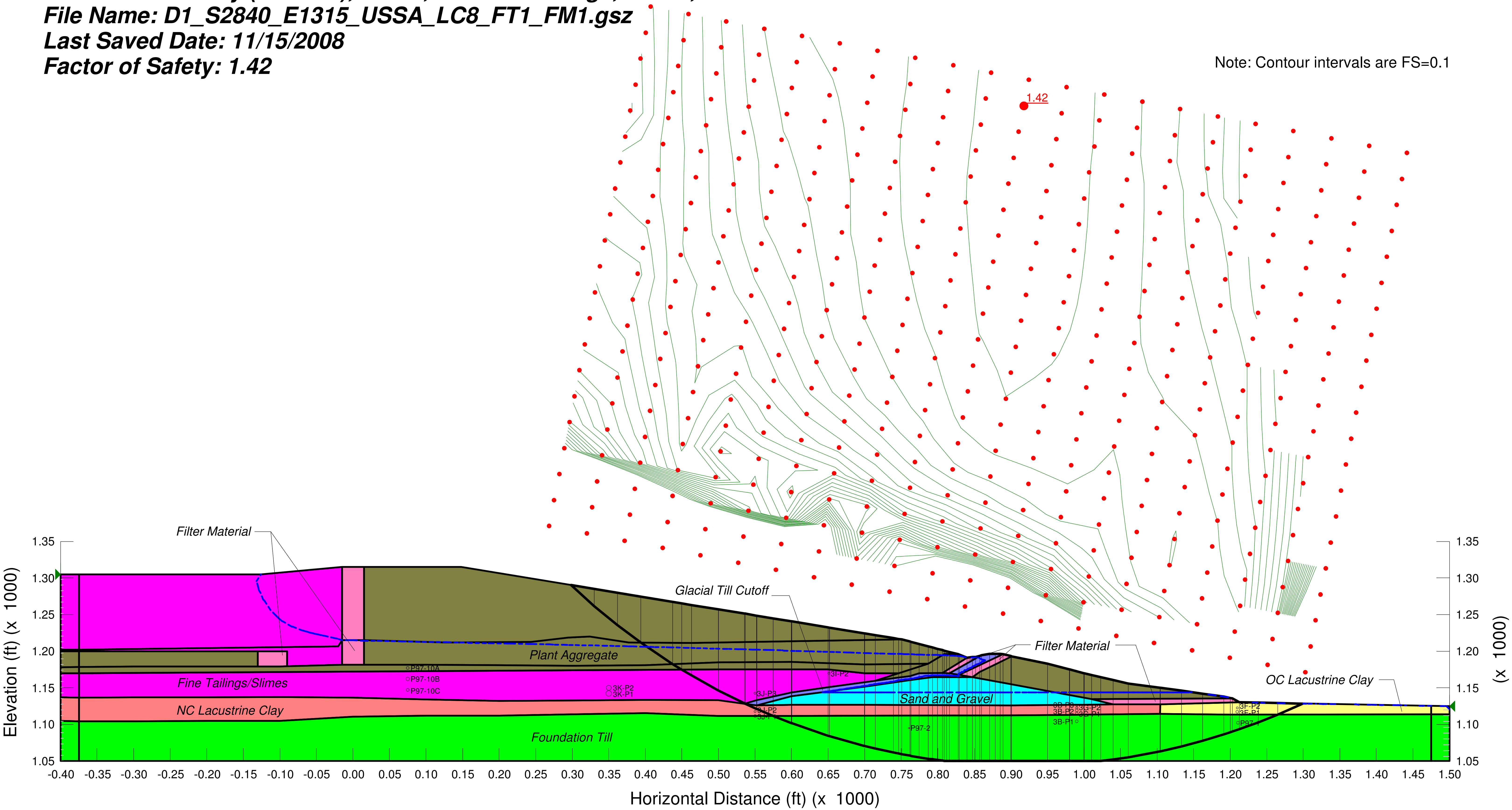


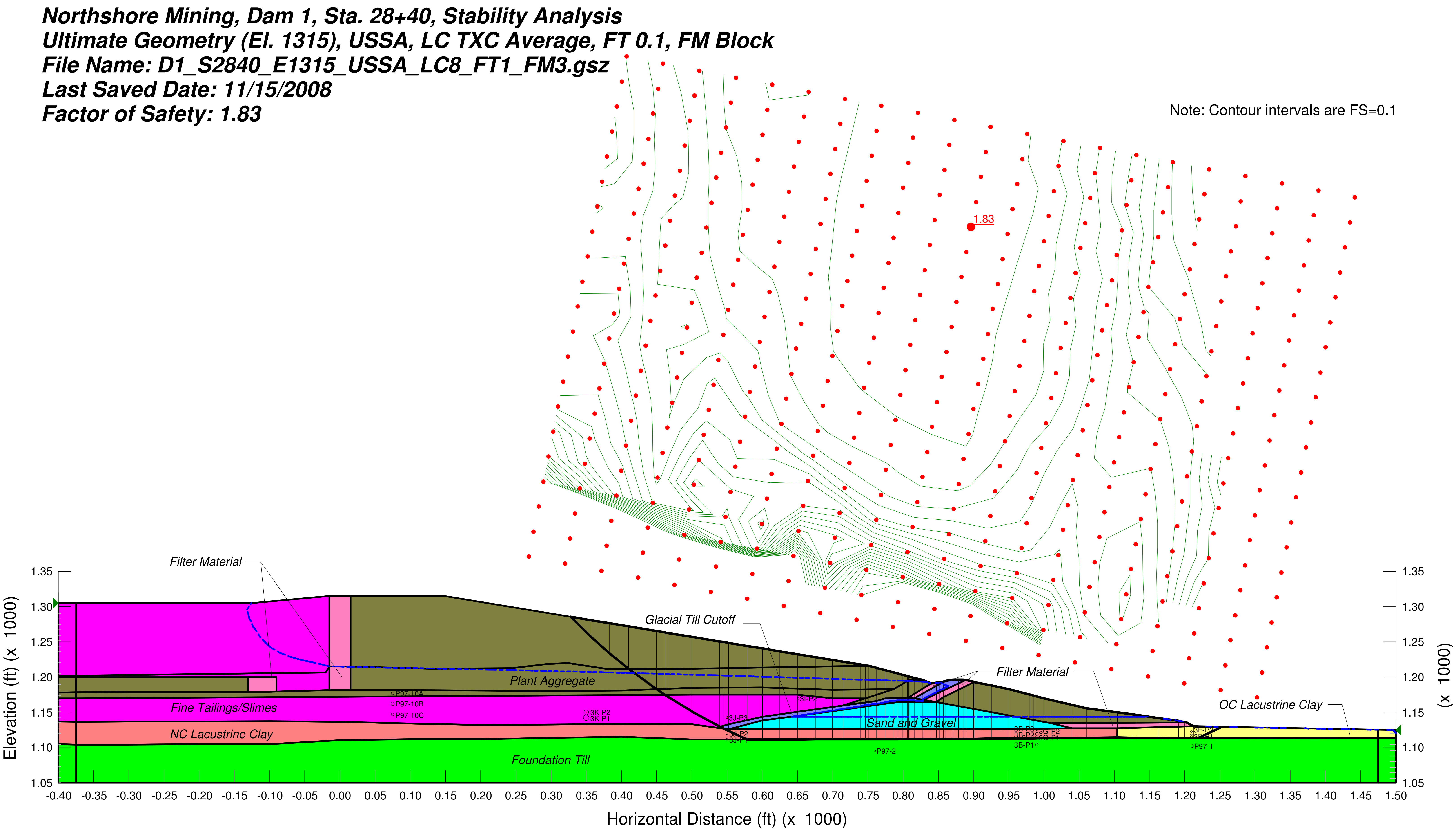

Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D1_S2840_E1315_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.41
Note: Contour intervals are FS=0.1
1.41
Filter Material
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Plant Aggregate
Fine Tailings/Slimes
NC Lacustrine Clay
Sand and Gravel
Foundation Till
P97-10A
P97-10B
P97-10C
3K-P2
3K-P1
Elevation (ft) (x 1000)
(x 1000)
Horizontal Distance (ft) (x 1000)
1.35
1.30
1.25
1.20
1.15
1.10
1.05
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50

Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.1, FM Block
File Name: D1_S2840_E1315_USSA_LC7_FT1_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.55



Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D1_S2840_E1315_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.42





Northshore Mining, Dam 1, Sta. 28+40, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D1_S2840_E1315_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 1.83
Note: Contour intervals are FS=0.1
1.83
Filter Material
Glacial Till Cutoff
Filter Material
Plant Aggregate
Fine Tailings/Slimes
NC Lacustrine Clay
Sand and Gravel
OC Lacustrine Clay
Foundation Till
Elevation (ft) (x 1000)
(x 1000)
Horizontal Distance (ft) (x 1000)
1.35
1.30
1.25
1.20
1.15
1.10
1.05
-0.40 -0.35 -0.30 -0.25 -0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30 1.35 1.40 1.45 1.50

Dam 2

Existing Geometry – Existing Conditions

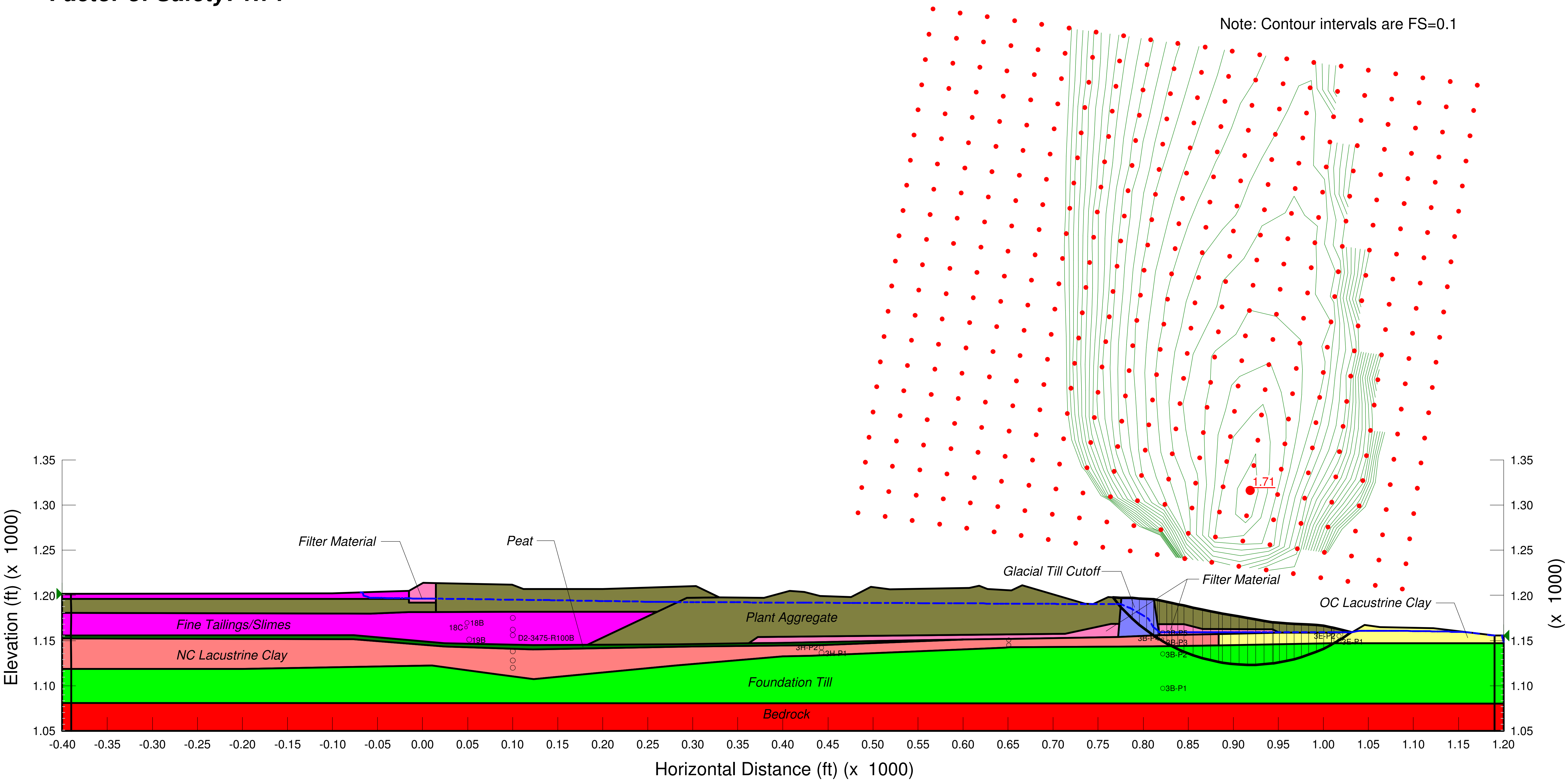
Proposed Geometry El. 1,230 feet

Proposed Geometry El. 1,245 feet

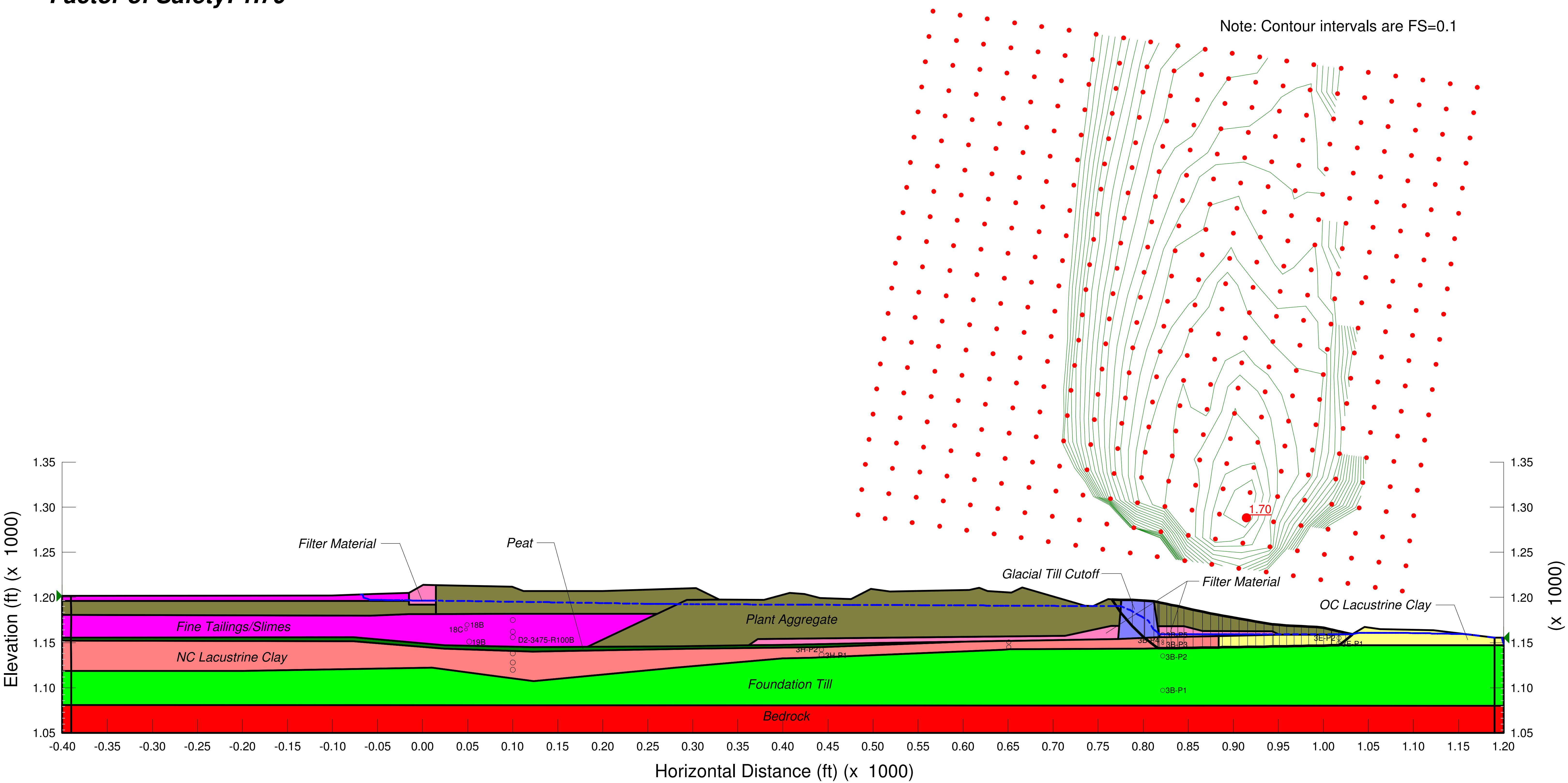
Proposed Geometry El. 1,315 feet

Existing Geometry – Existing Conditions

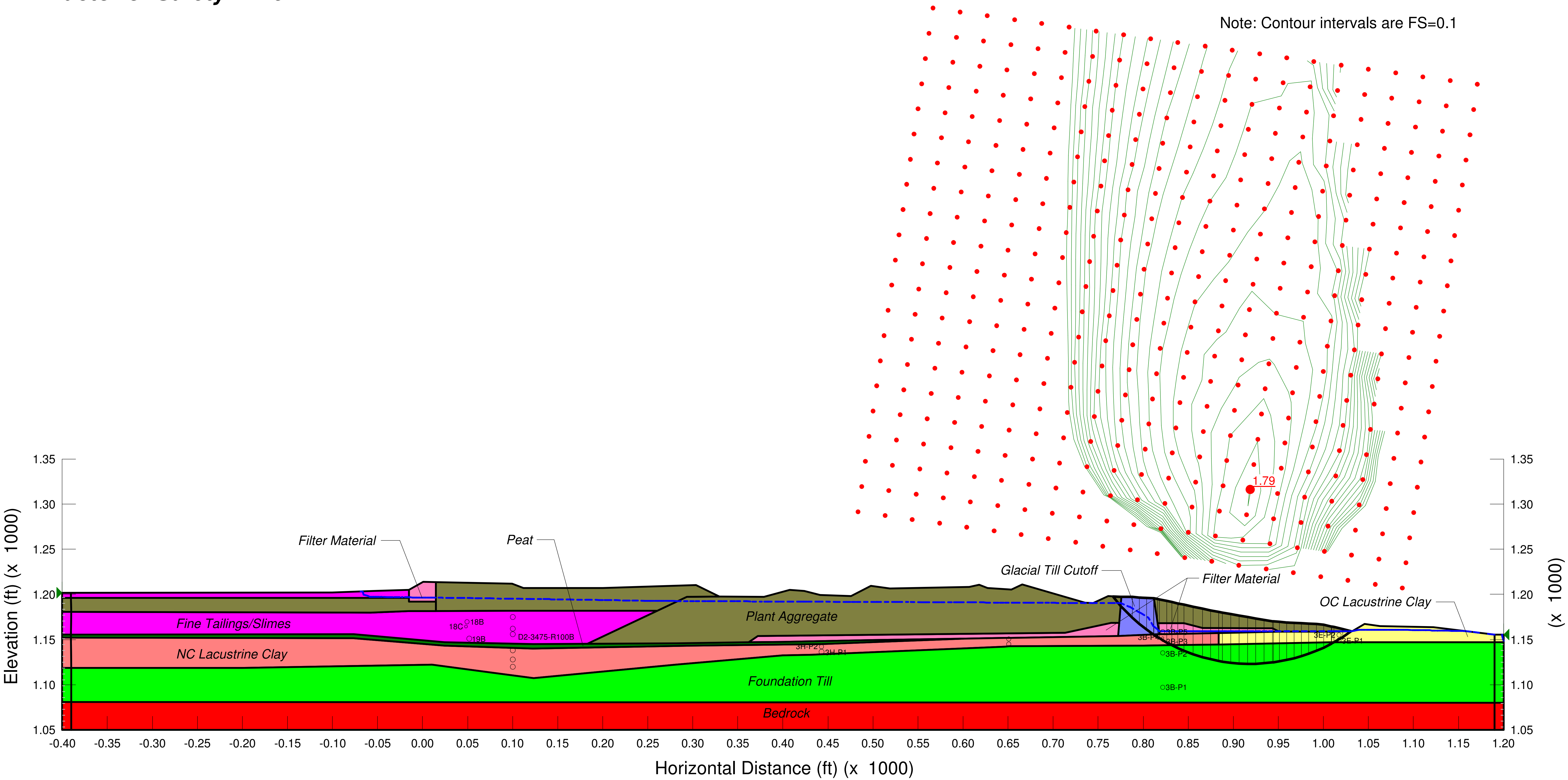
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D2_S3475_E1215_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.71



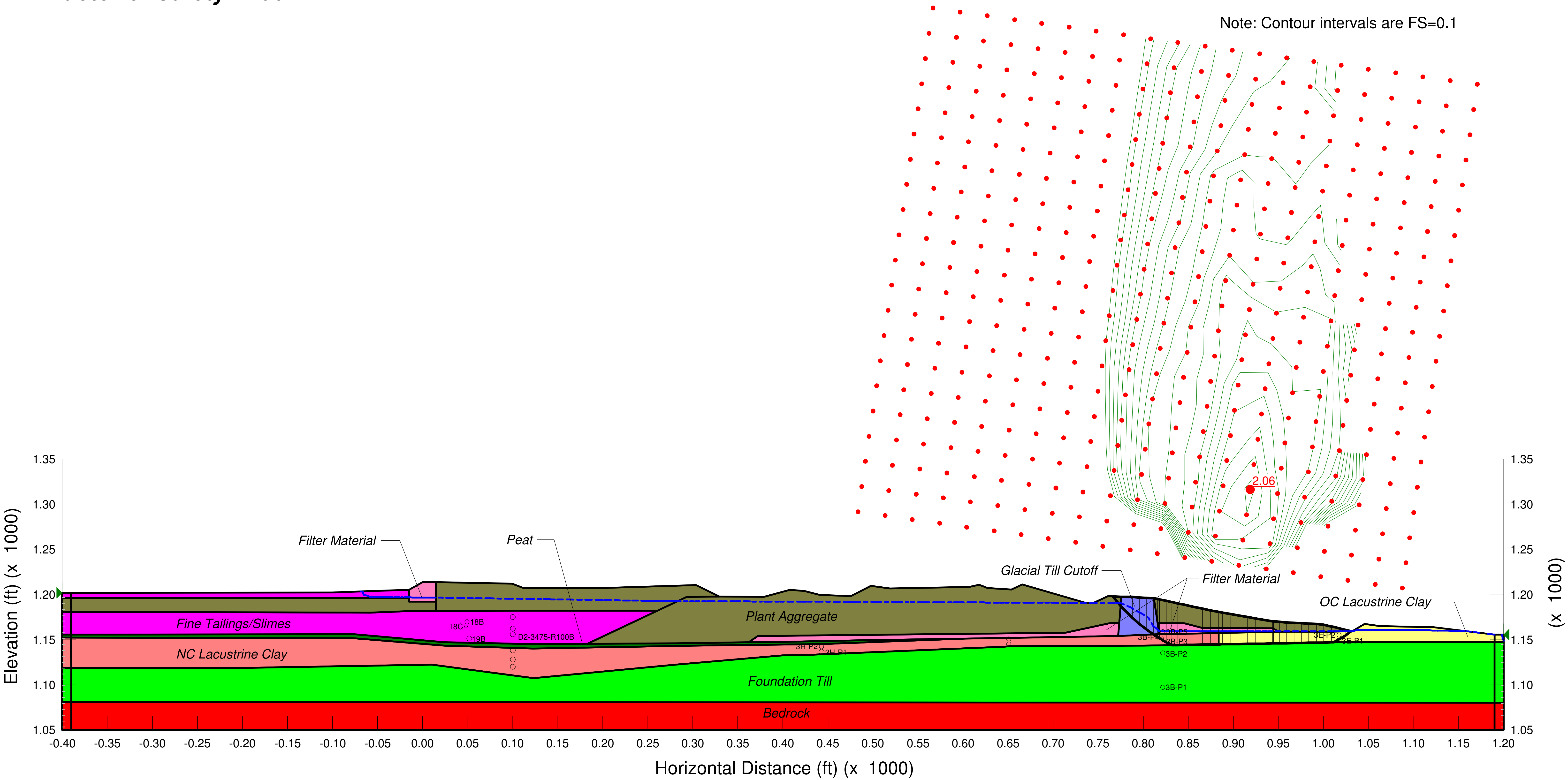
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D2_S3475_E1215_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.70



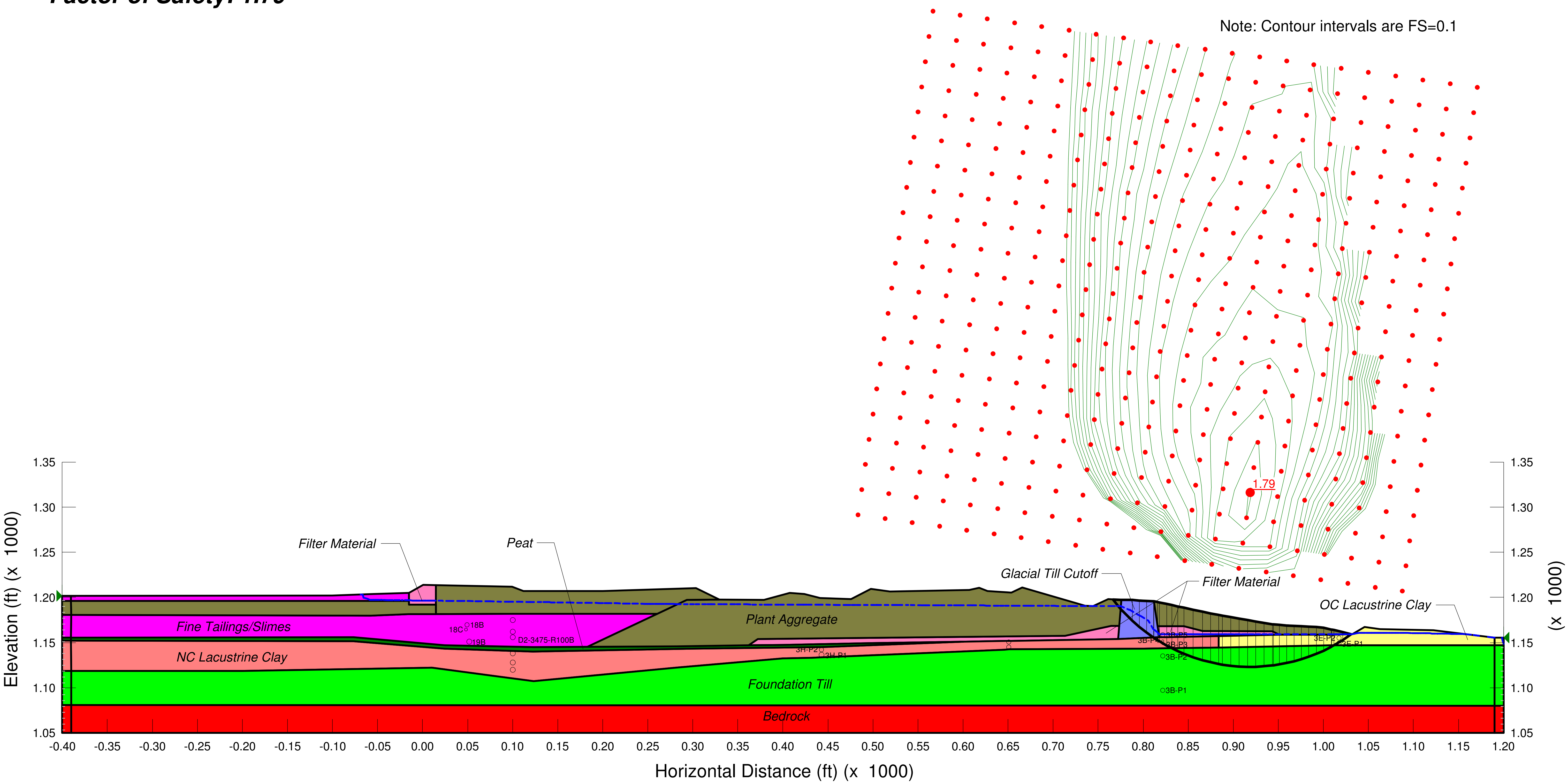
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D2_S3475_E1215_USSA_LC6_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.79



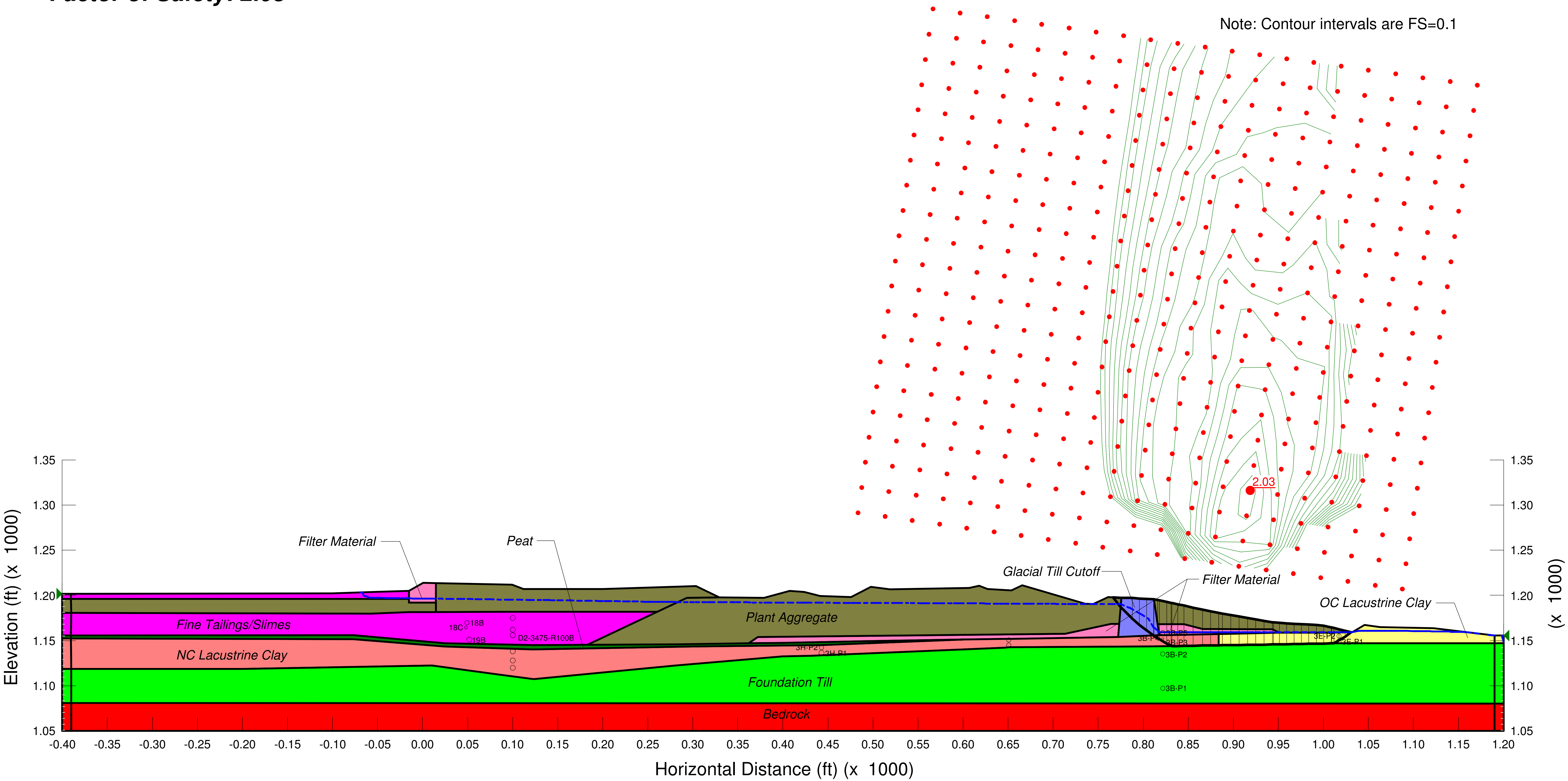
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.2, FM Block
File Name: D2_S3475_E1215_USSA_LC6_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.06



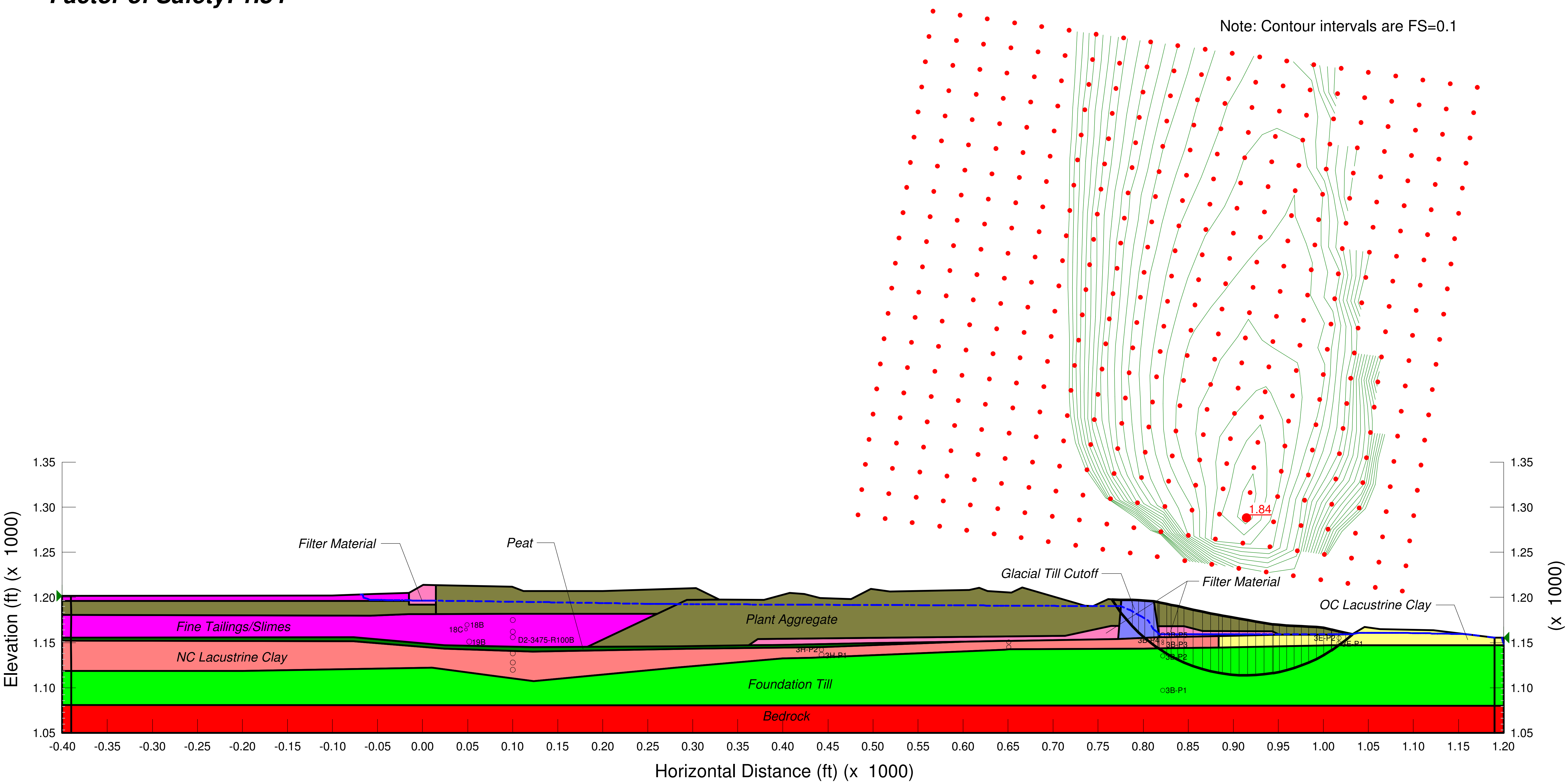
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.2, FM Toe
File Name: D2_S3475_E1215_USSA_LC7_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.79



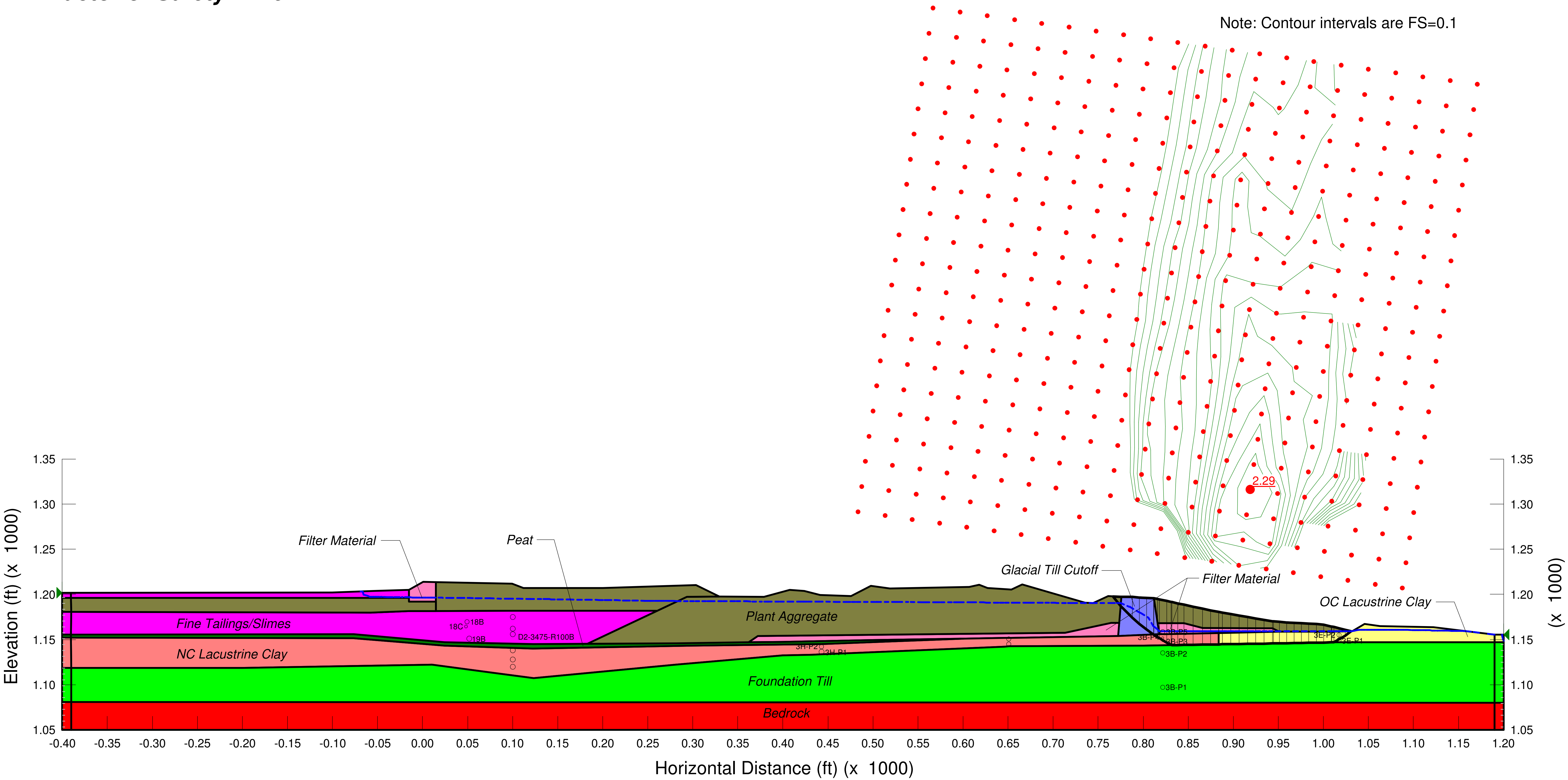
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.2, FM Block
File Name: D2_S3475_E1215_USSA_LC7_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.03



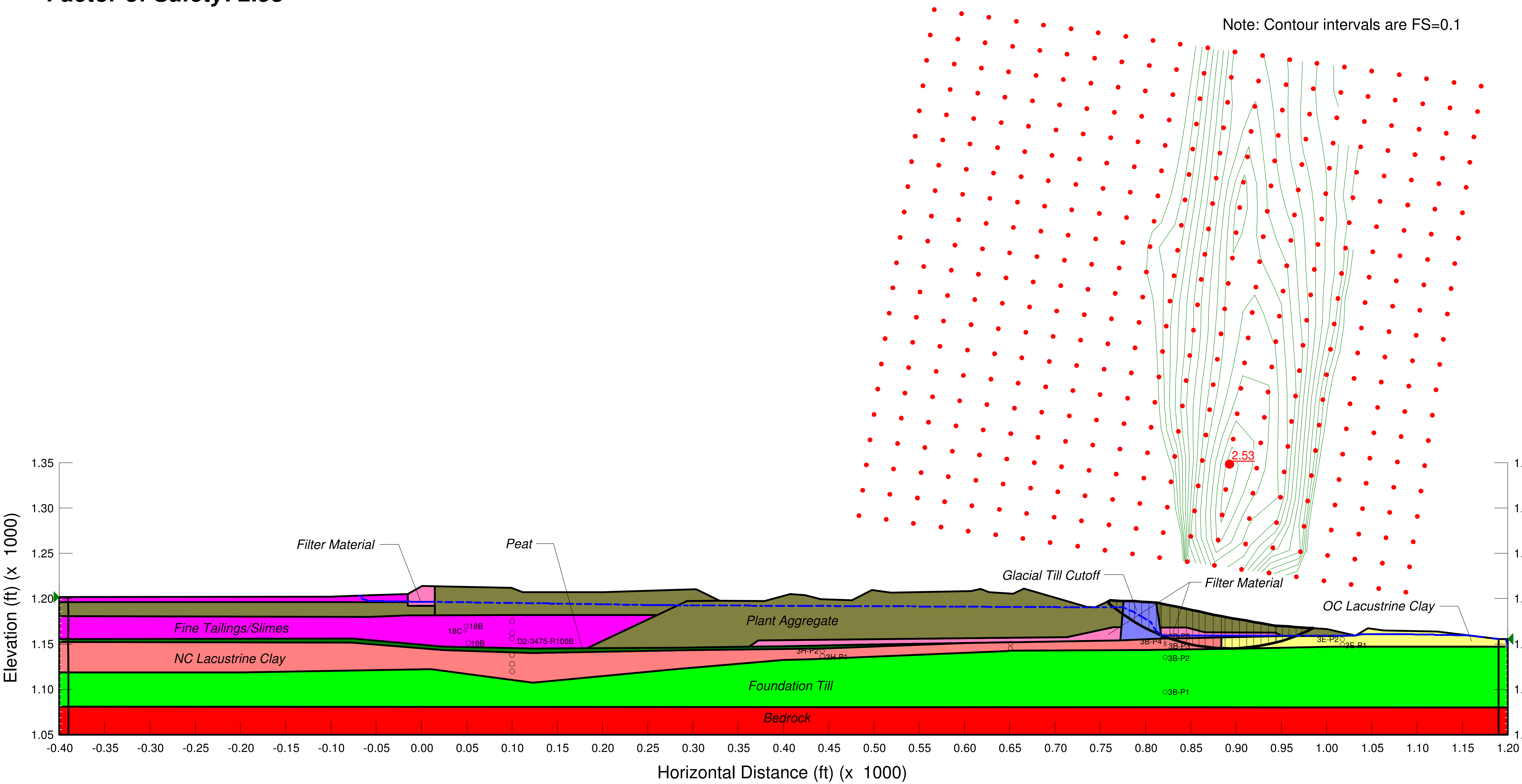
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D2_S3475_E1215_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.84



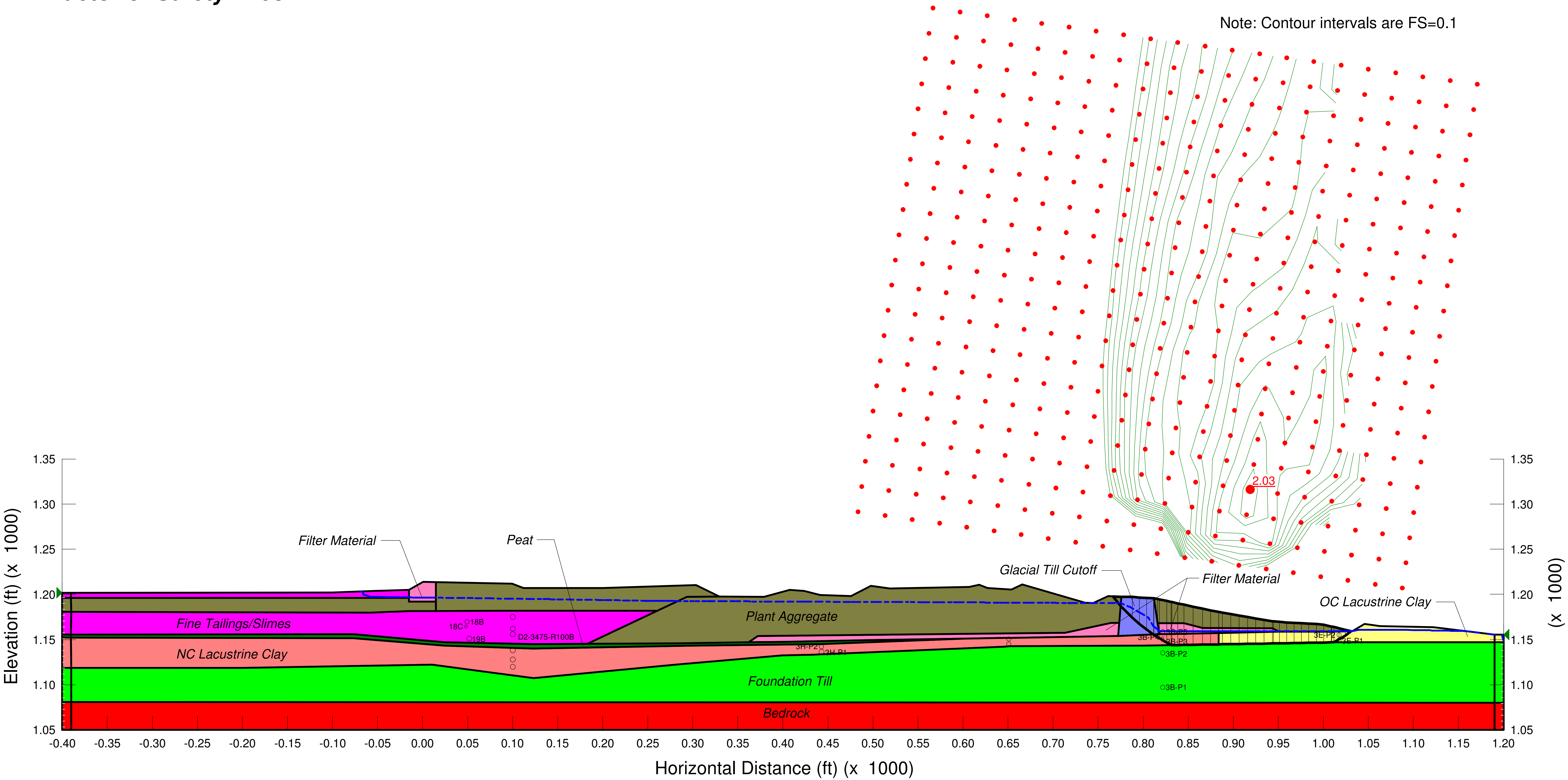
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D2_S3475_E1215_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.29



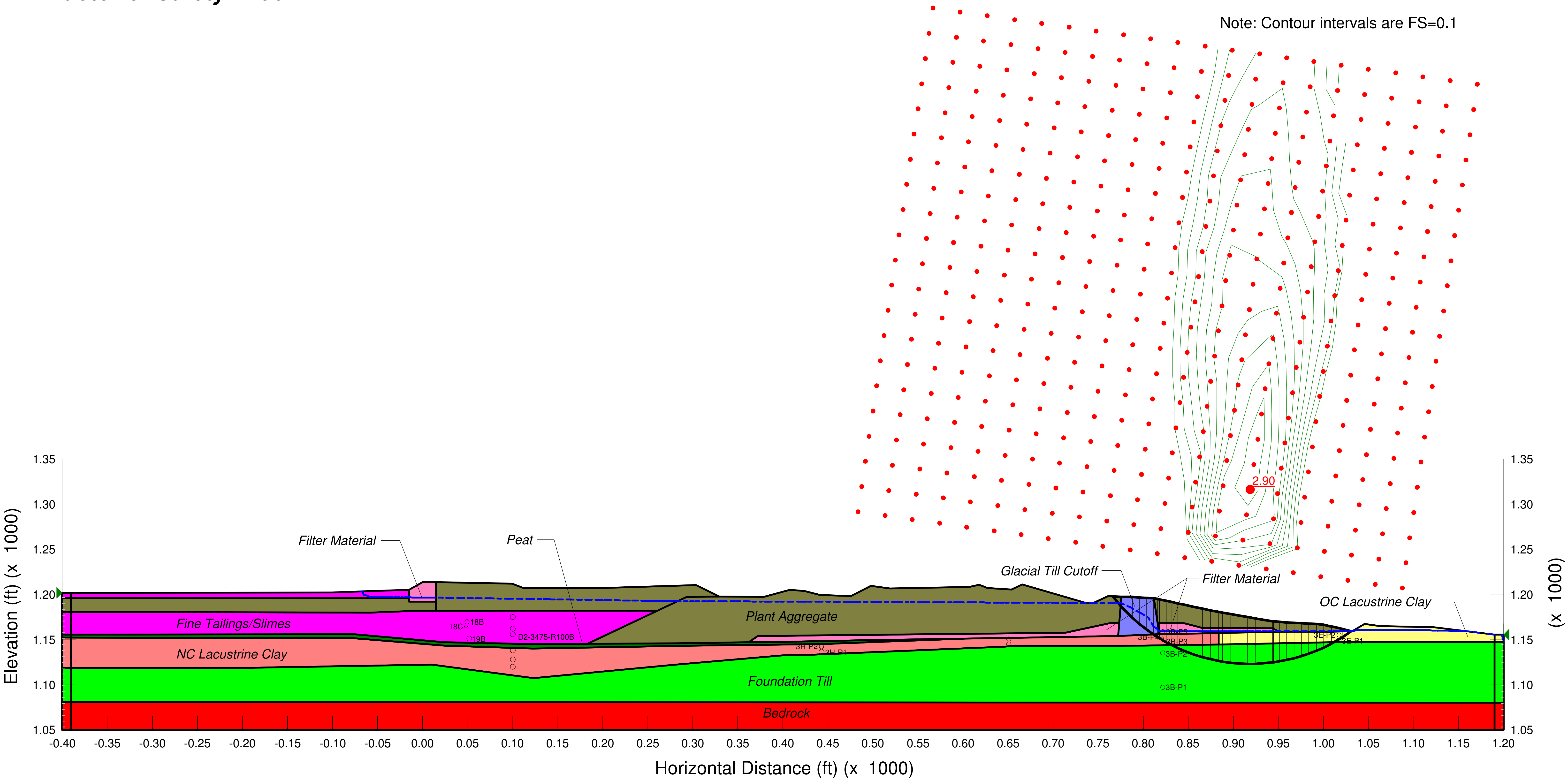
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC DSS Low, FM Toe
File Name: D2_S3475_E1215_ESSA_LC1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.53



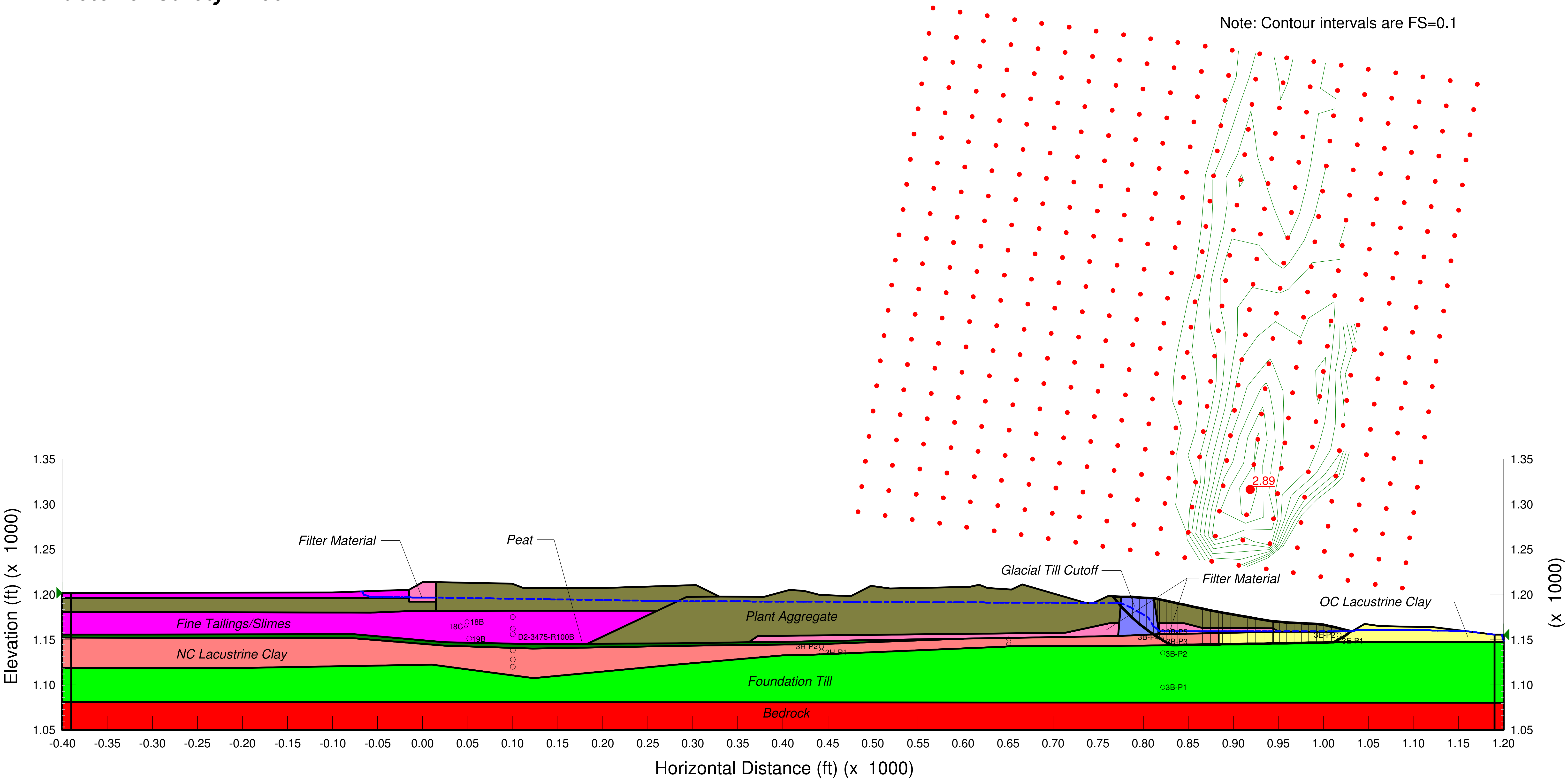
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC DSS Low, FM Block
File Name: D2_S3475_E1215_ESSA_LC1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.03



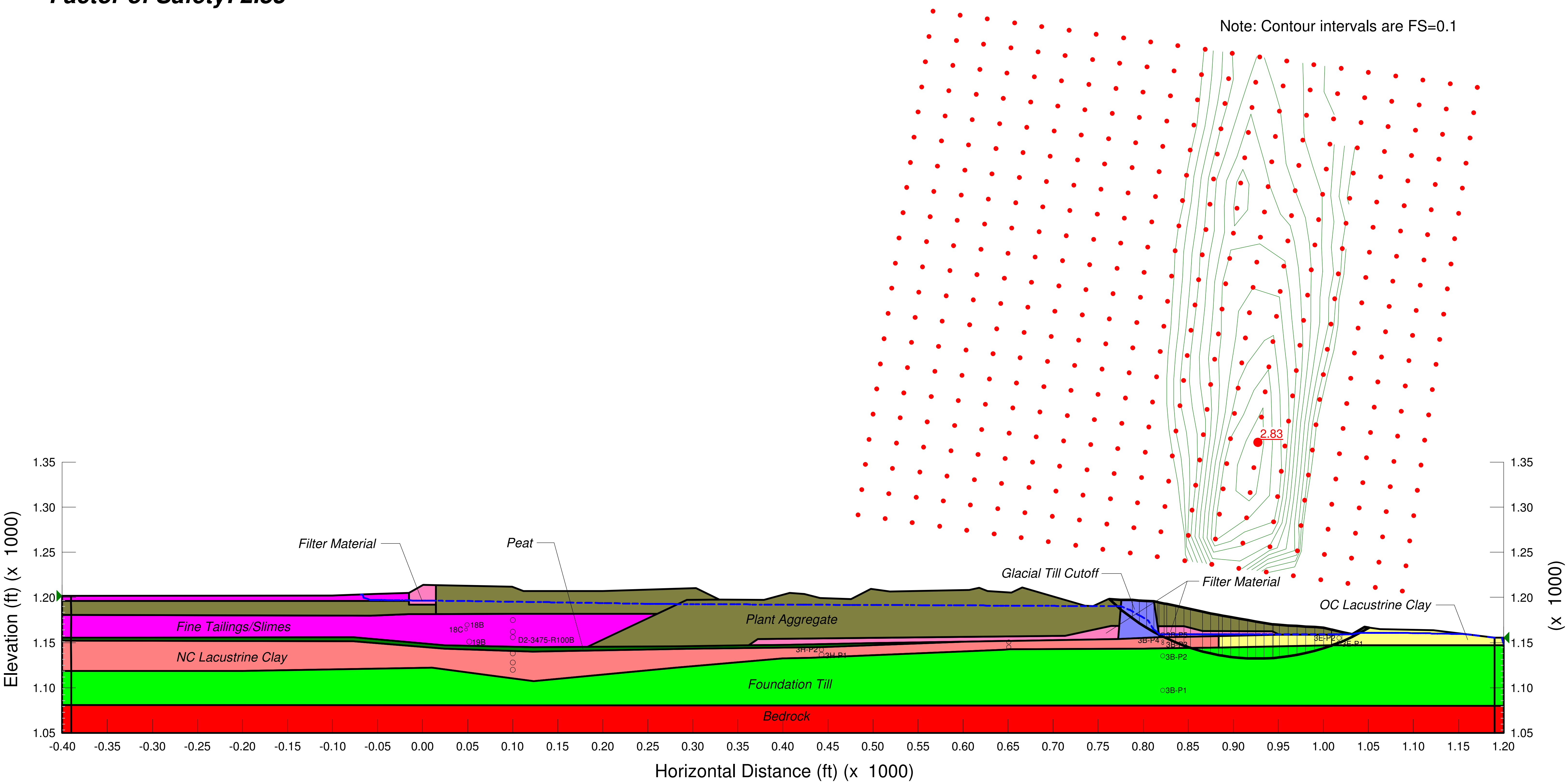
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC DSS Average, FM Toe
File Name: D2_S3475_E1215_ESSA_LC2_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.90



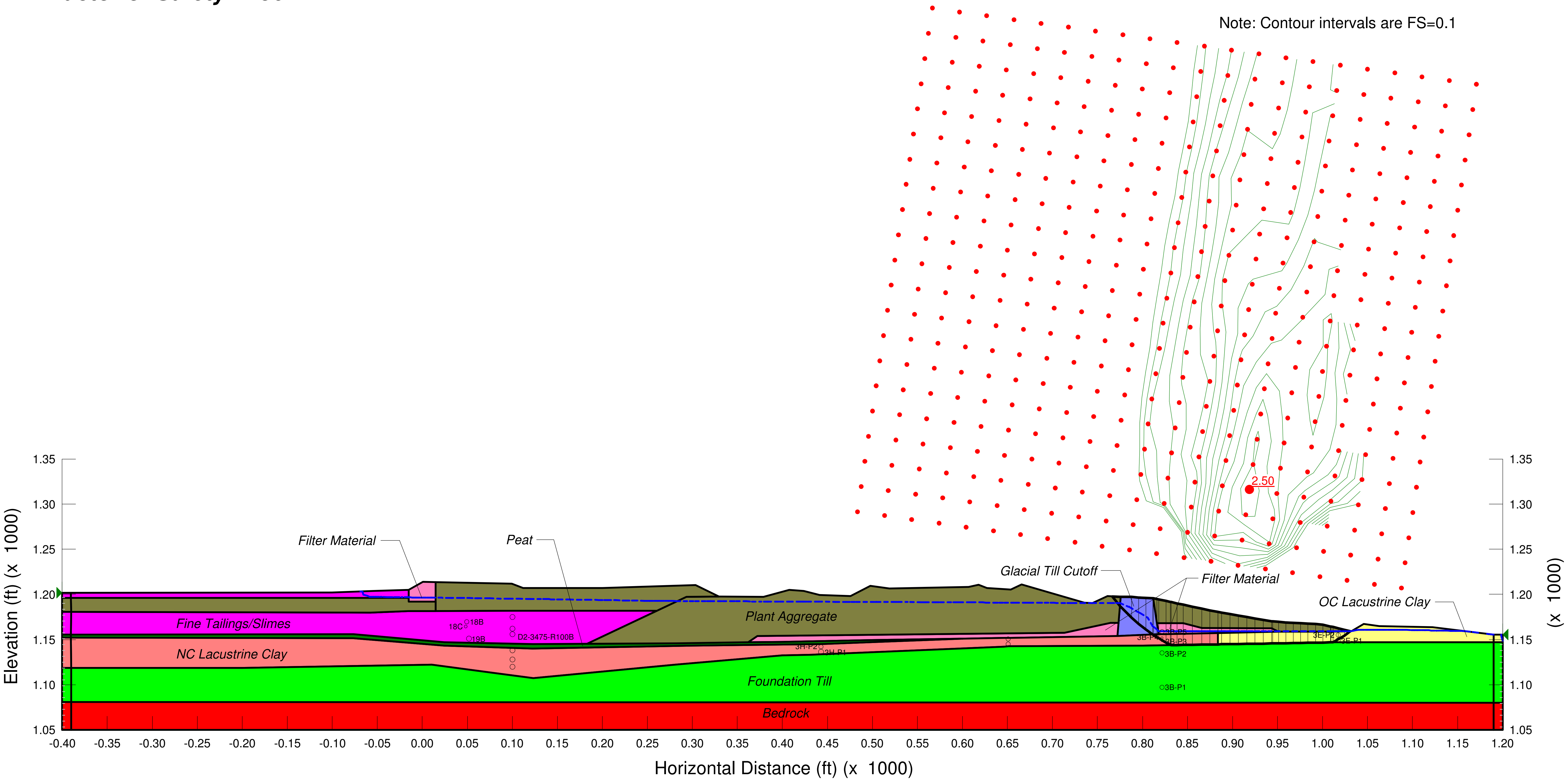
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC DSS Average, FM Block
File Name: D2_S3475_E1215_ESSA_LC2_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.89



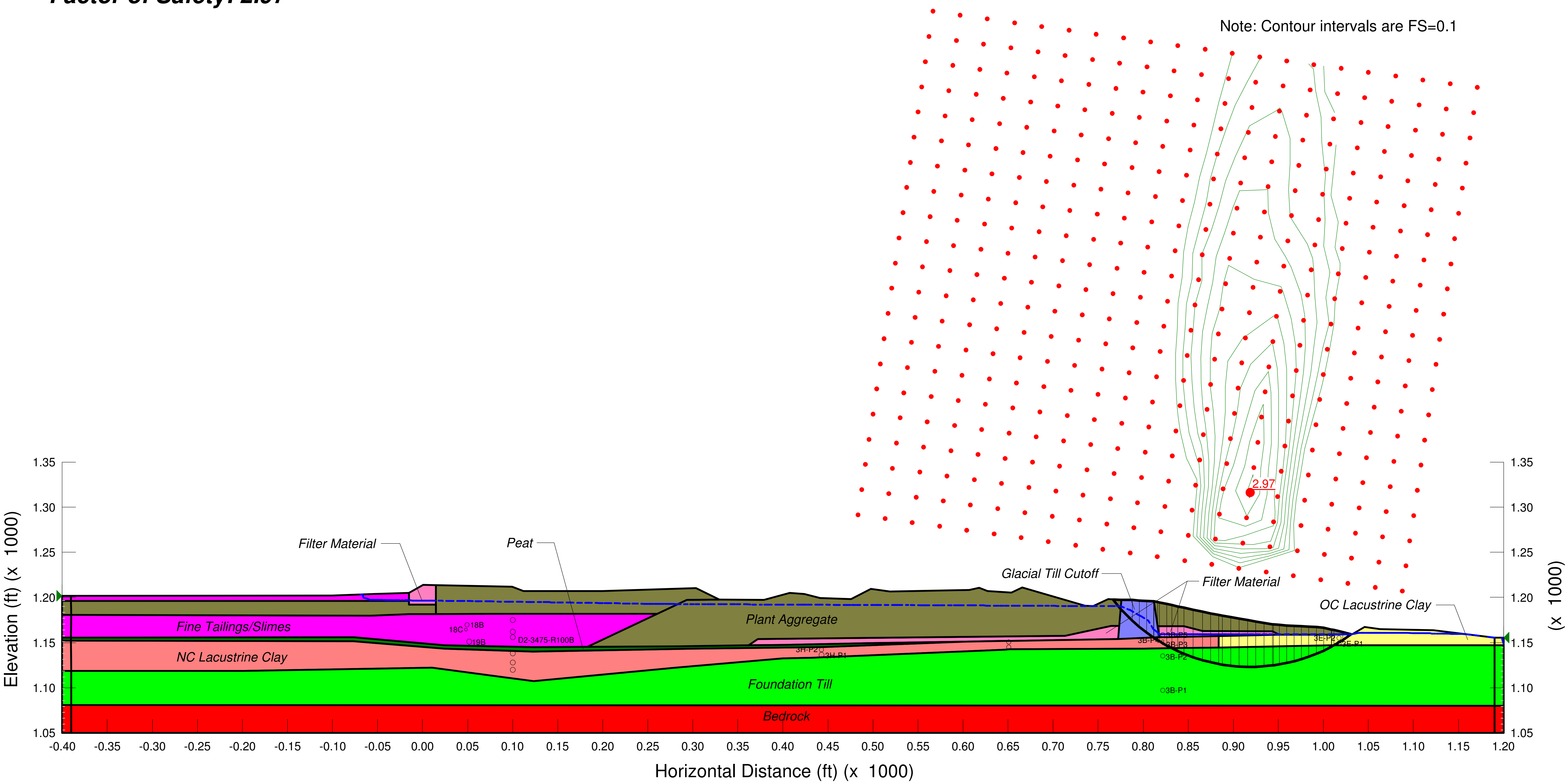
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Low, FM Toe
File Name: D2_S3475_E1215_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.83



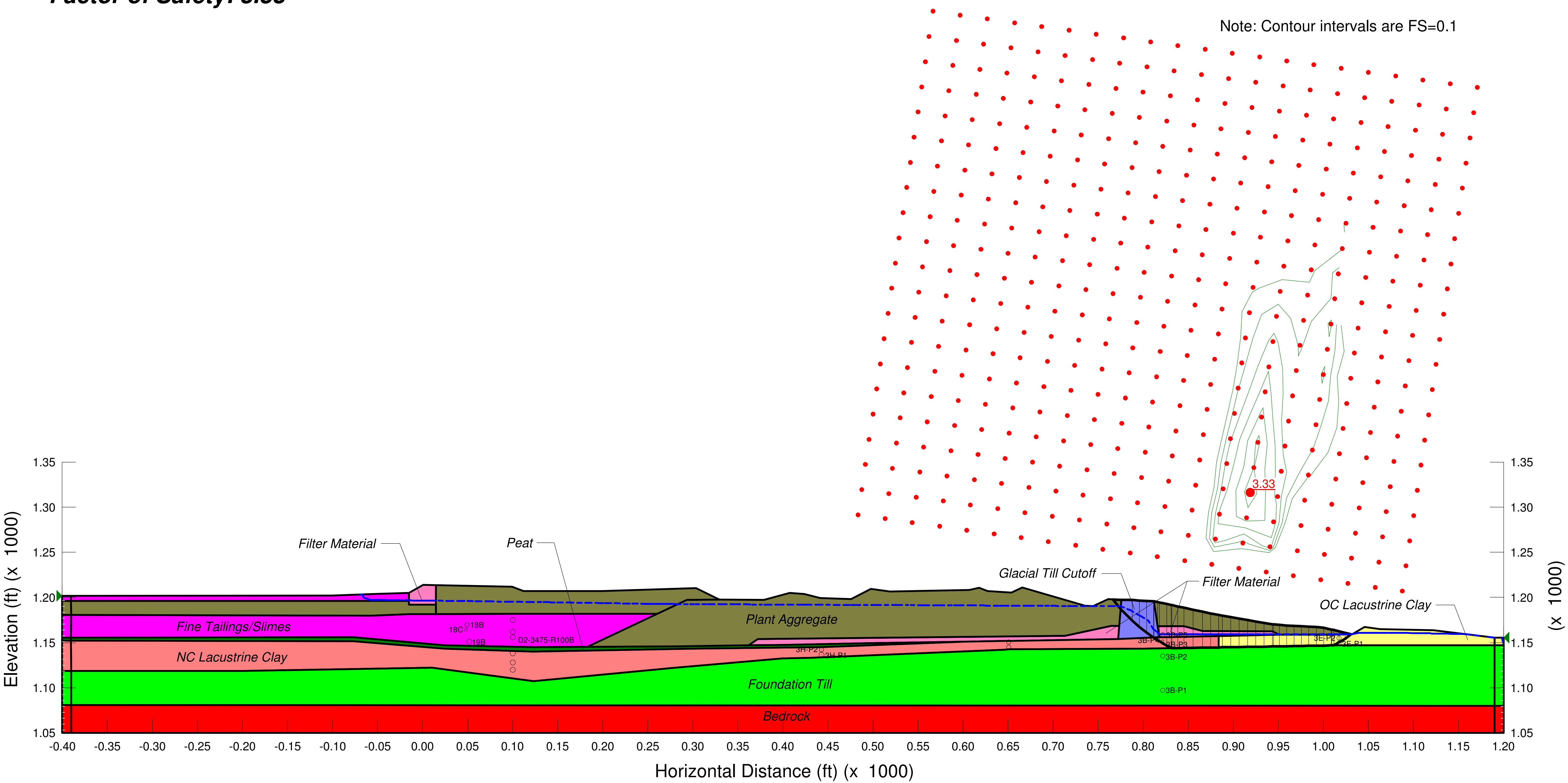
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Low, FM Block
File Name: D2_S3475_E1215_ESSA_LC3_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.50



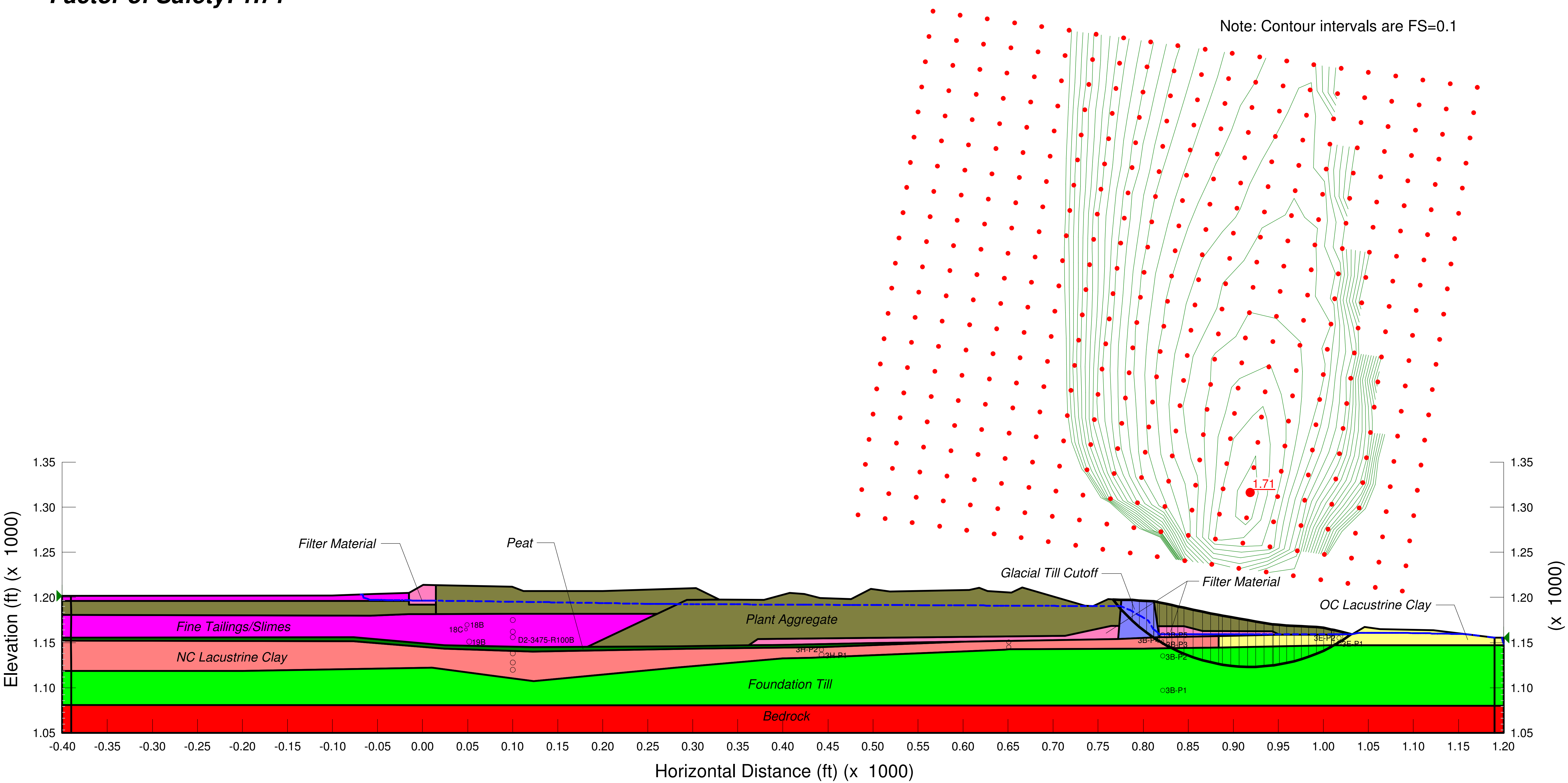
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Average, FM Toe
File Name: D2_S3475_E1215_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.97



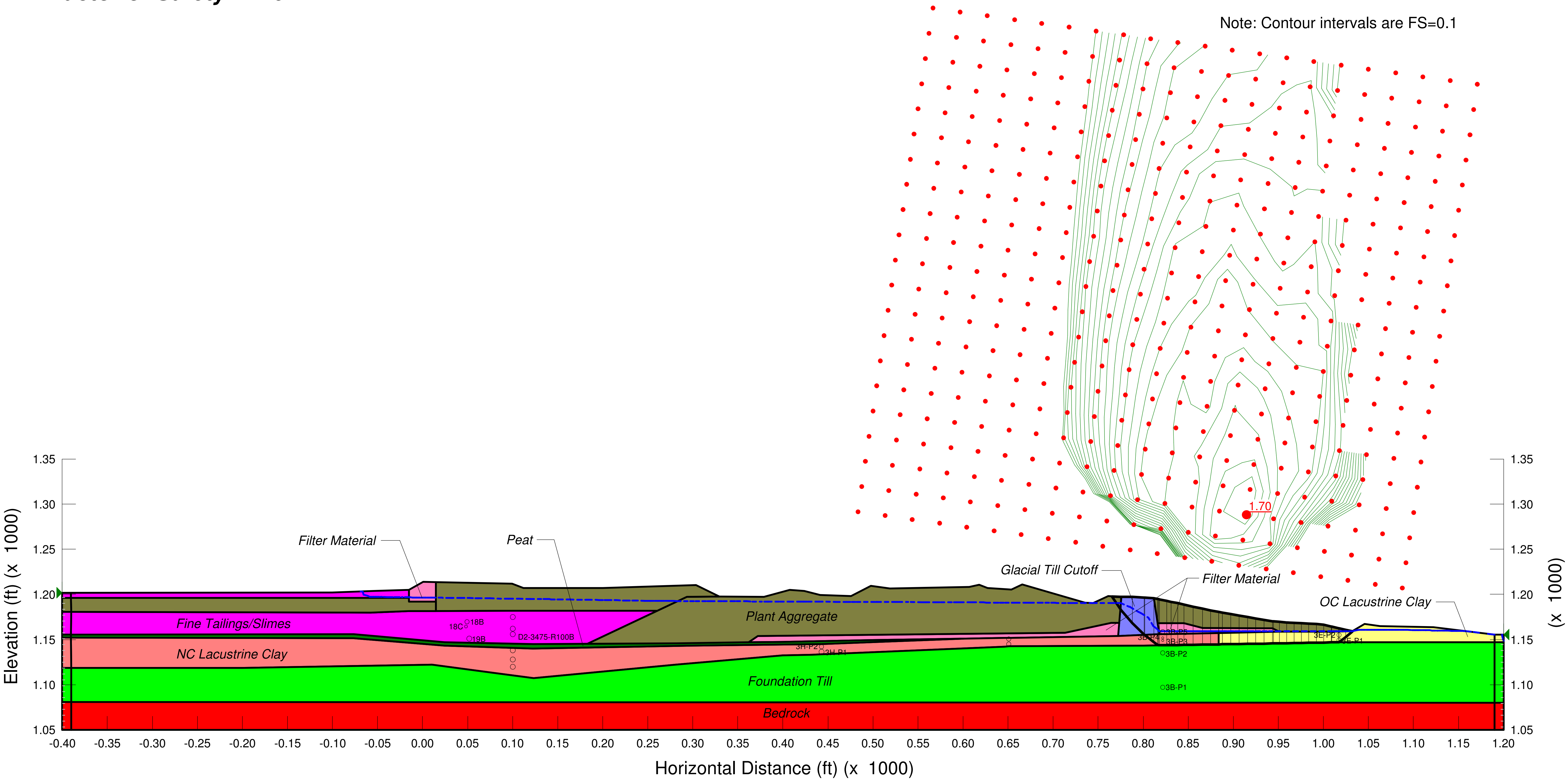
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), ESSA, LC TXC Average, FM Block
File Name: D2_S3475_E1215_ESSA_LC4_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 3.33



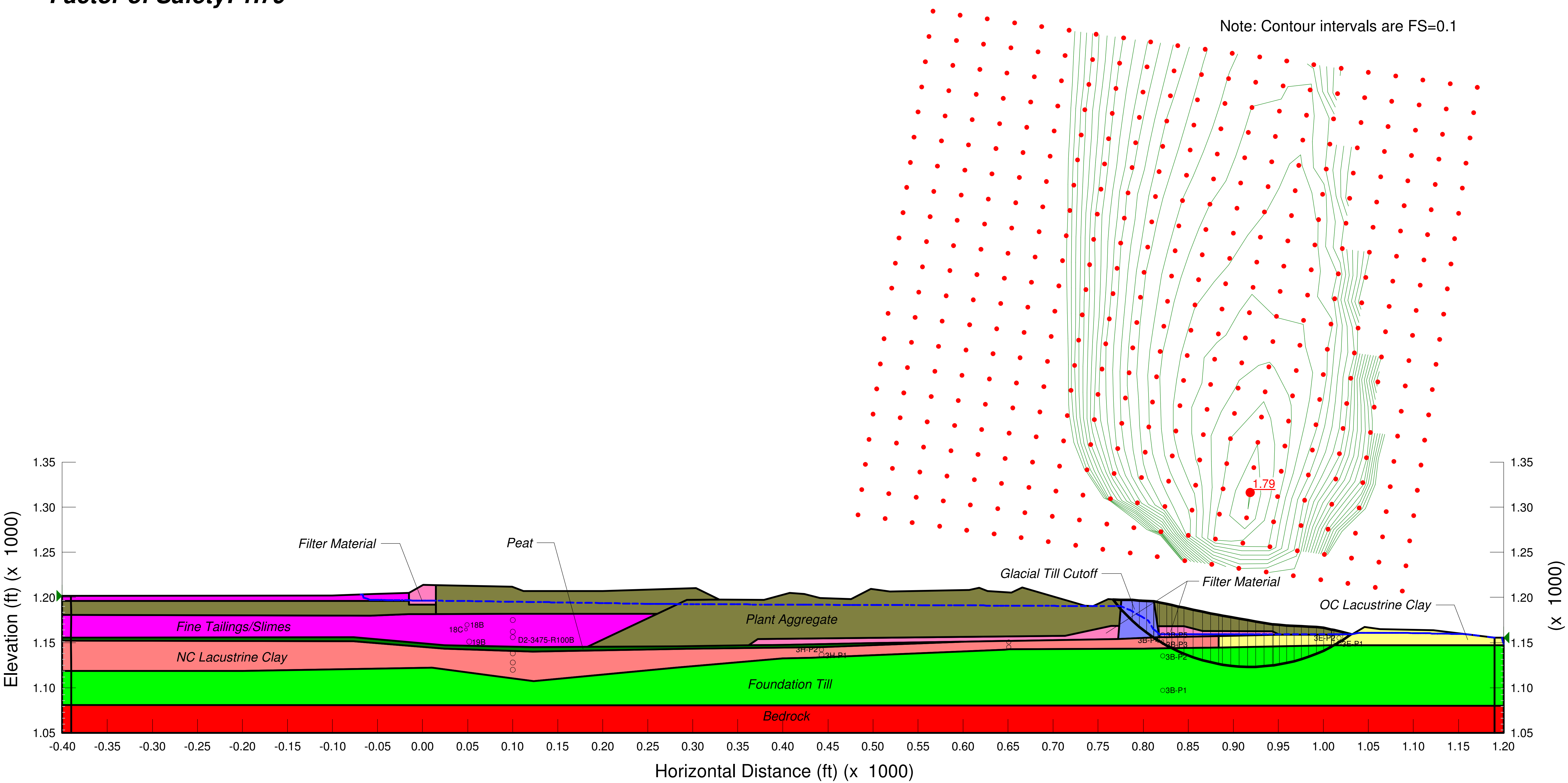
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D2_S3475_E1215_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.71



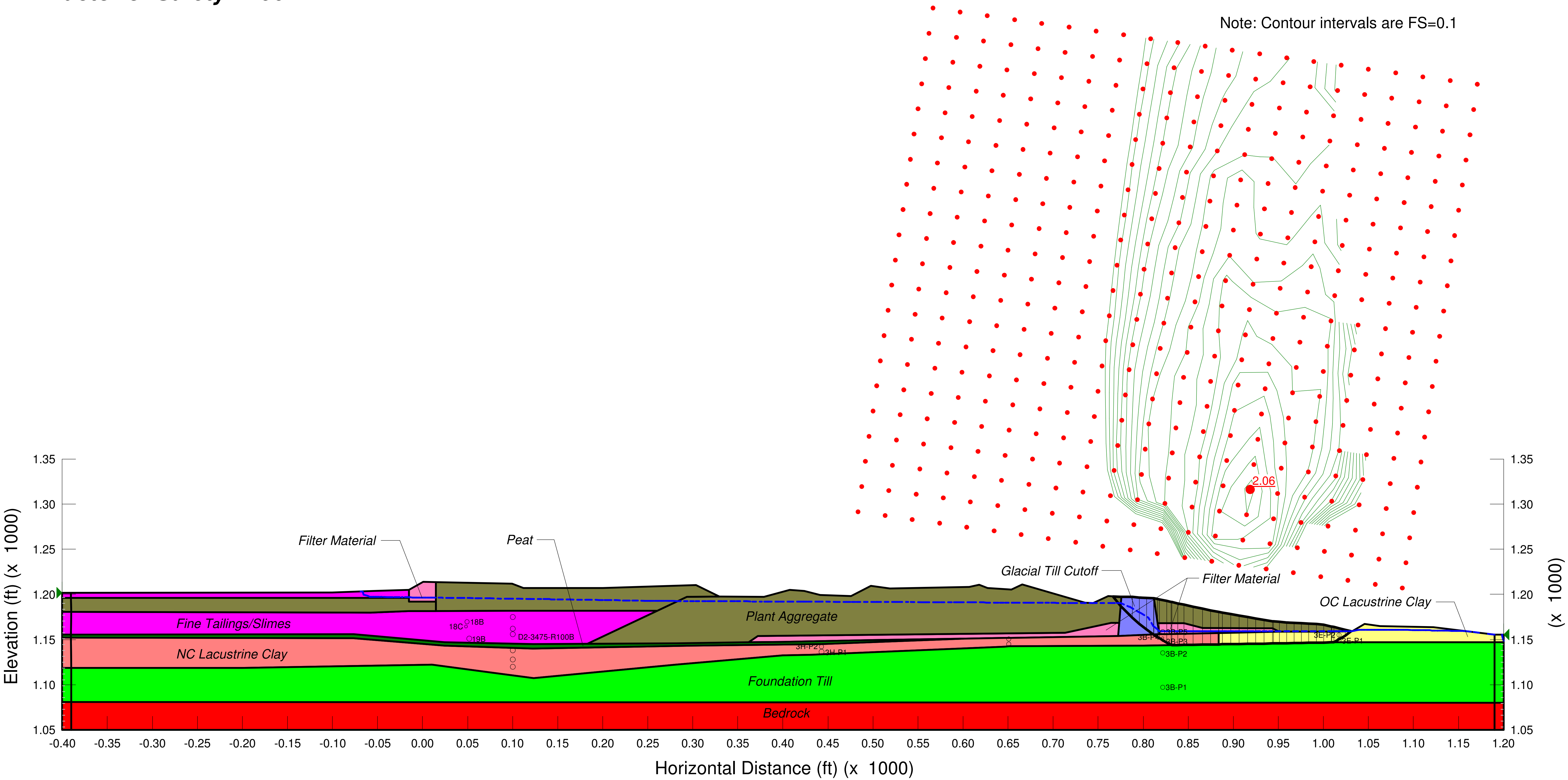
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D2_S3475_E1215_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.70



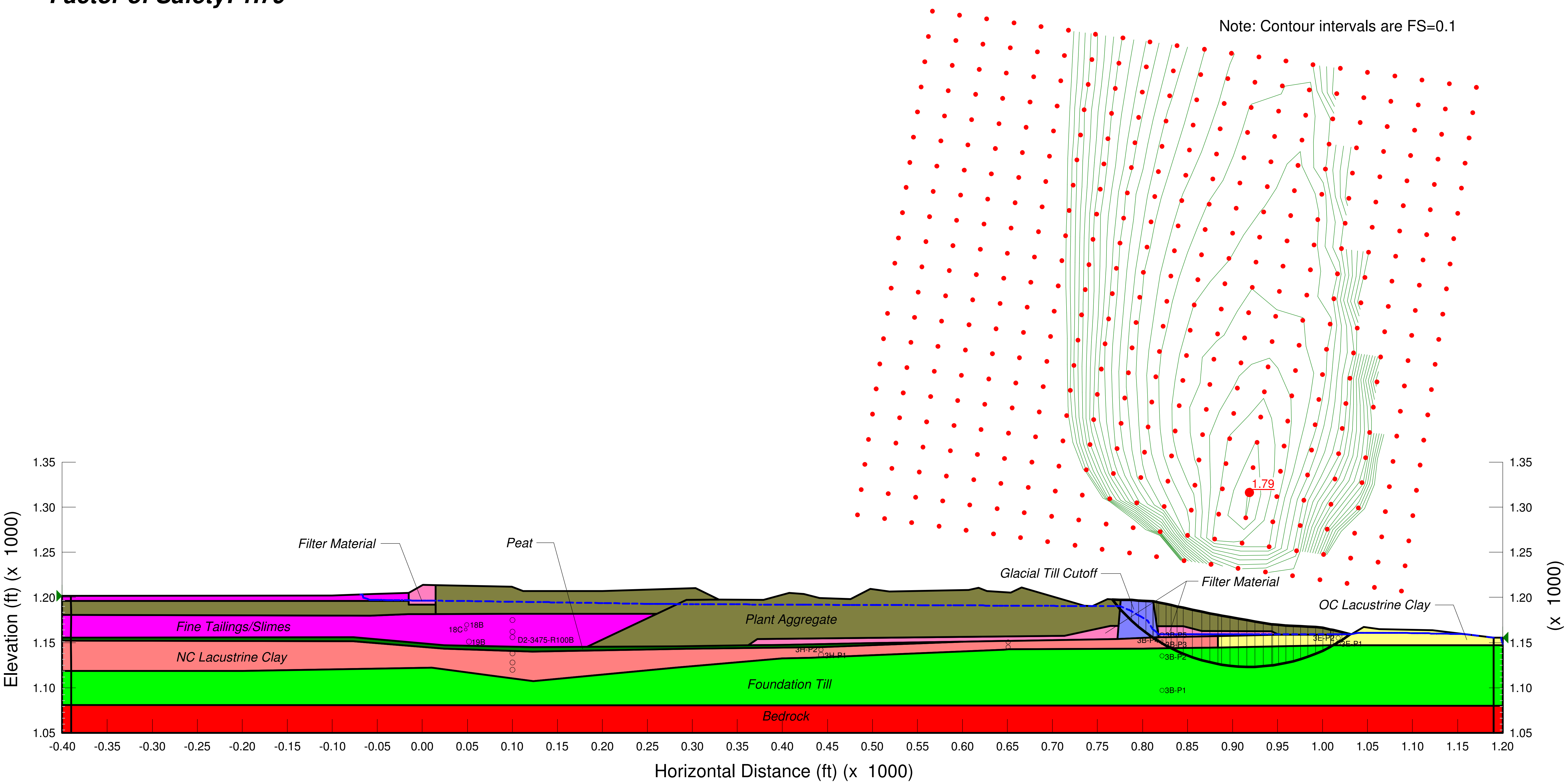
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D2_S3475_E1215_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.79



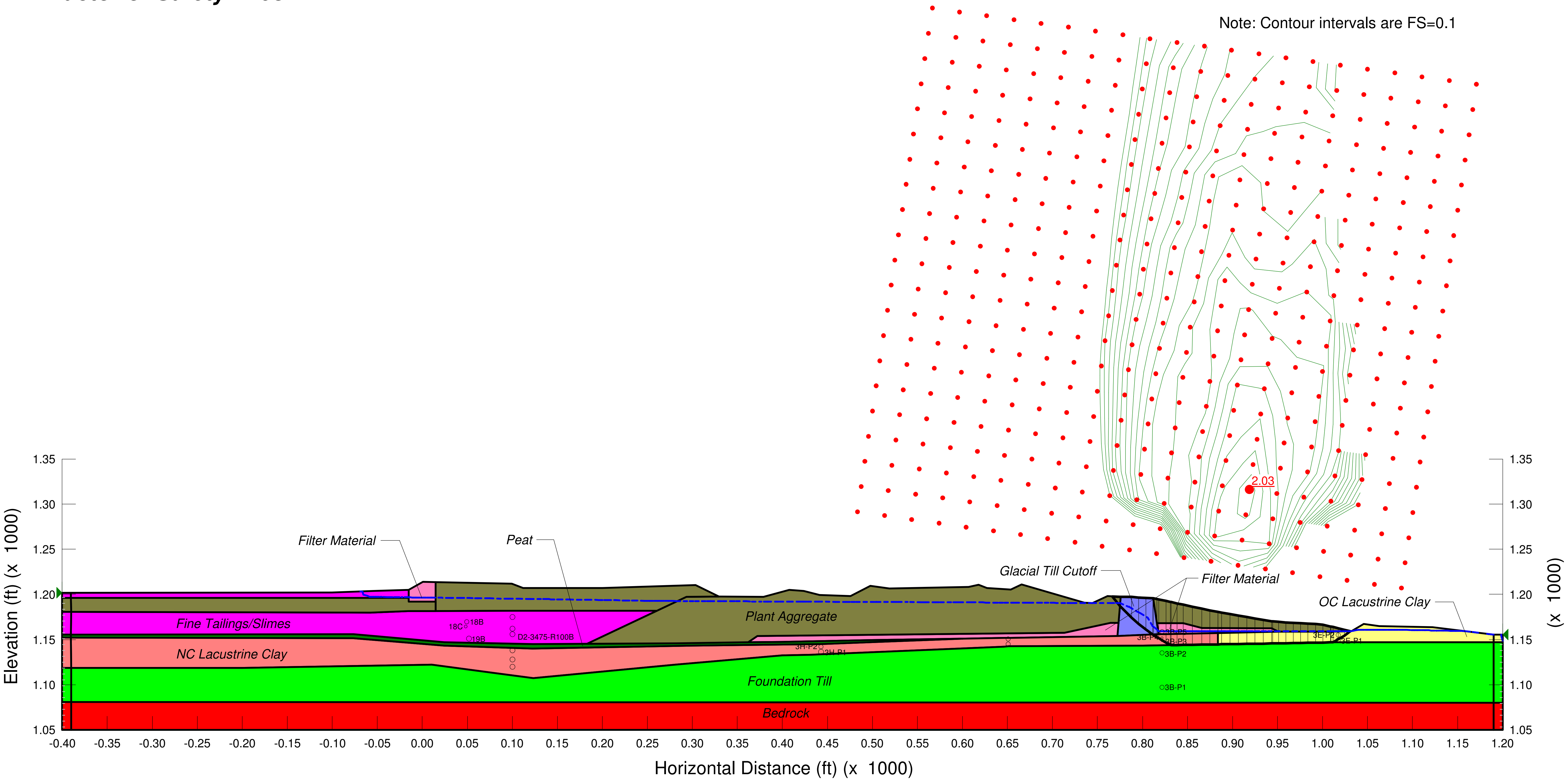
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC DSS Average, FT 0.1, FM Block
_File Name: D2_S3475_E1215_USSA_LC6_FT1_FM3.gsz_
Last Saved Date: 11/17/2008
Factor of Safety: 2.06



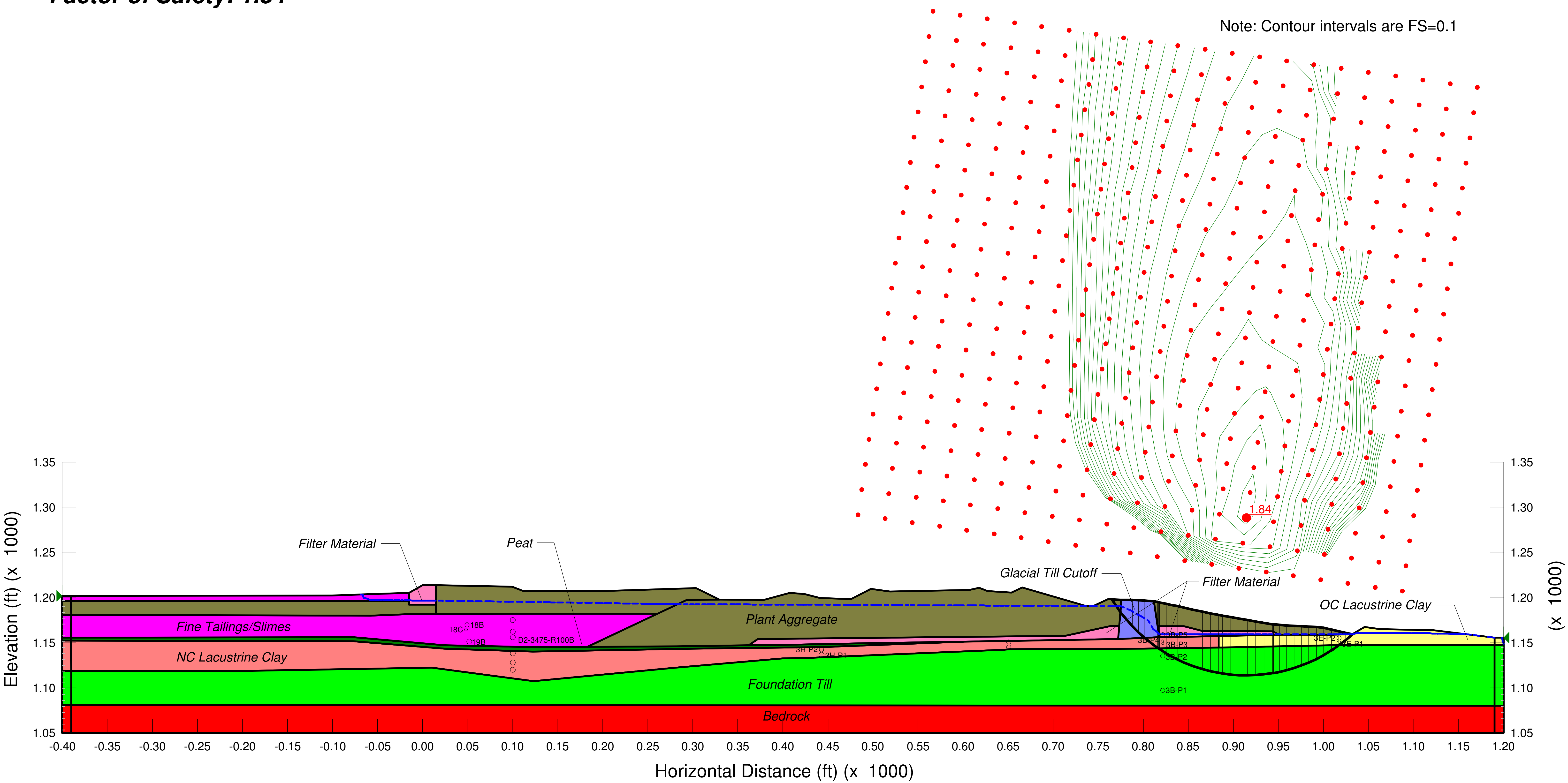
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D2_S3475_E1215_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.79



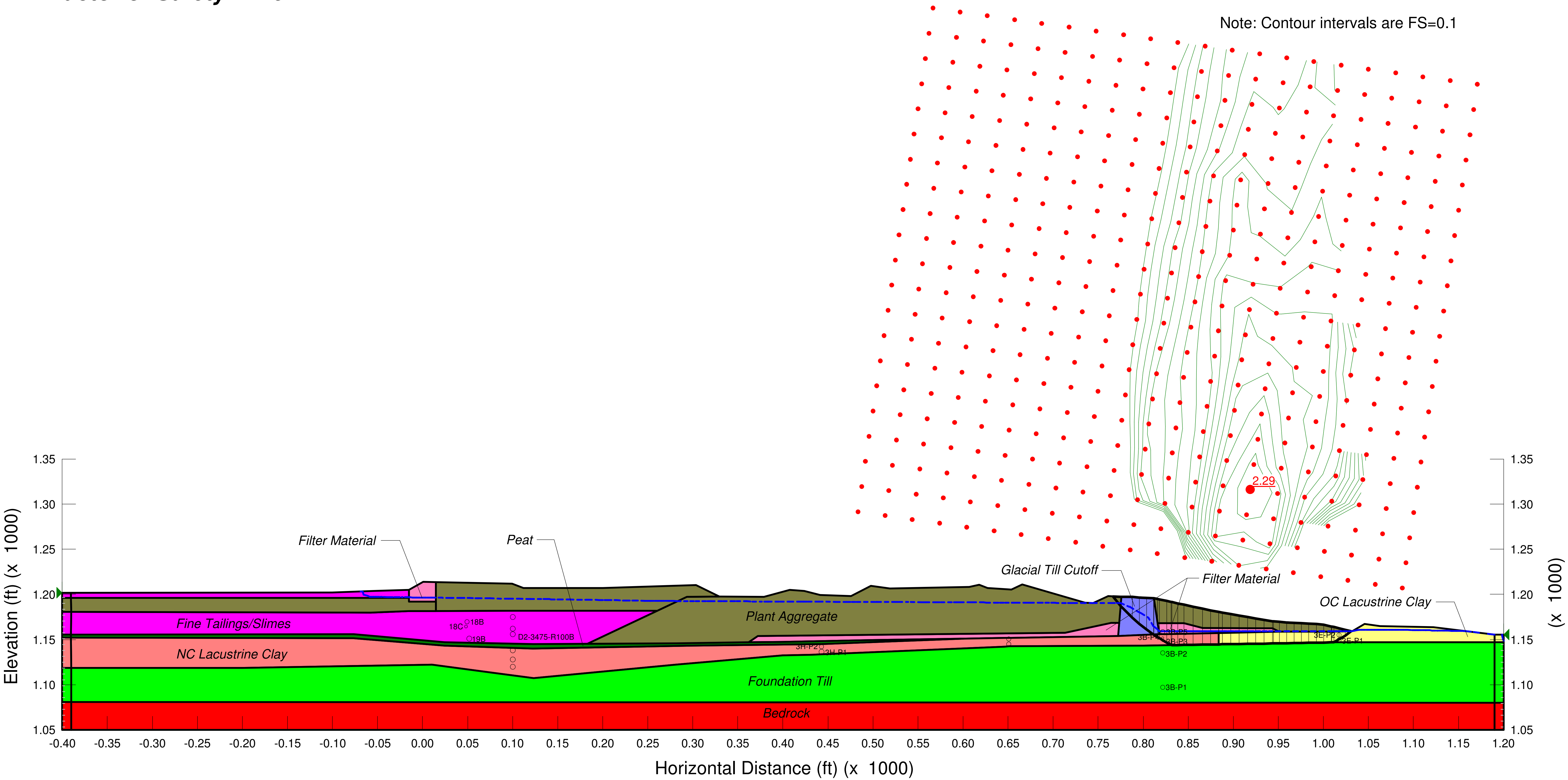
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Low, FT 0.1, FM Block
File Name: D2_S3475_E1215_USSA_LC7_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.03



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D2_S3475_E1215_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.84

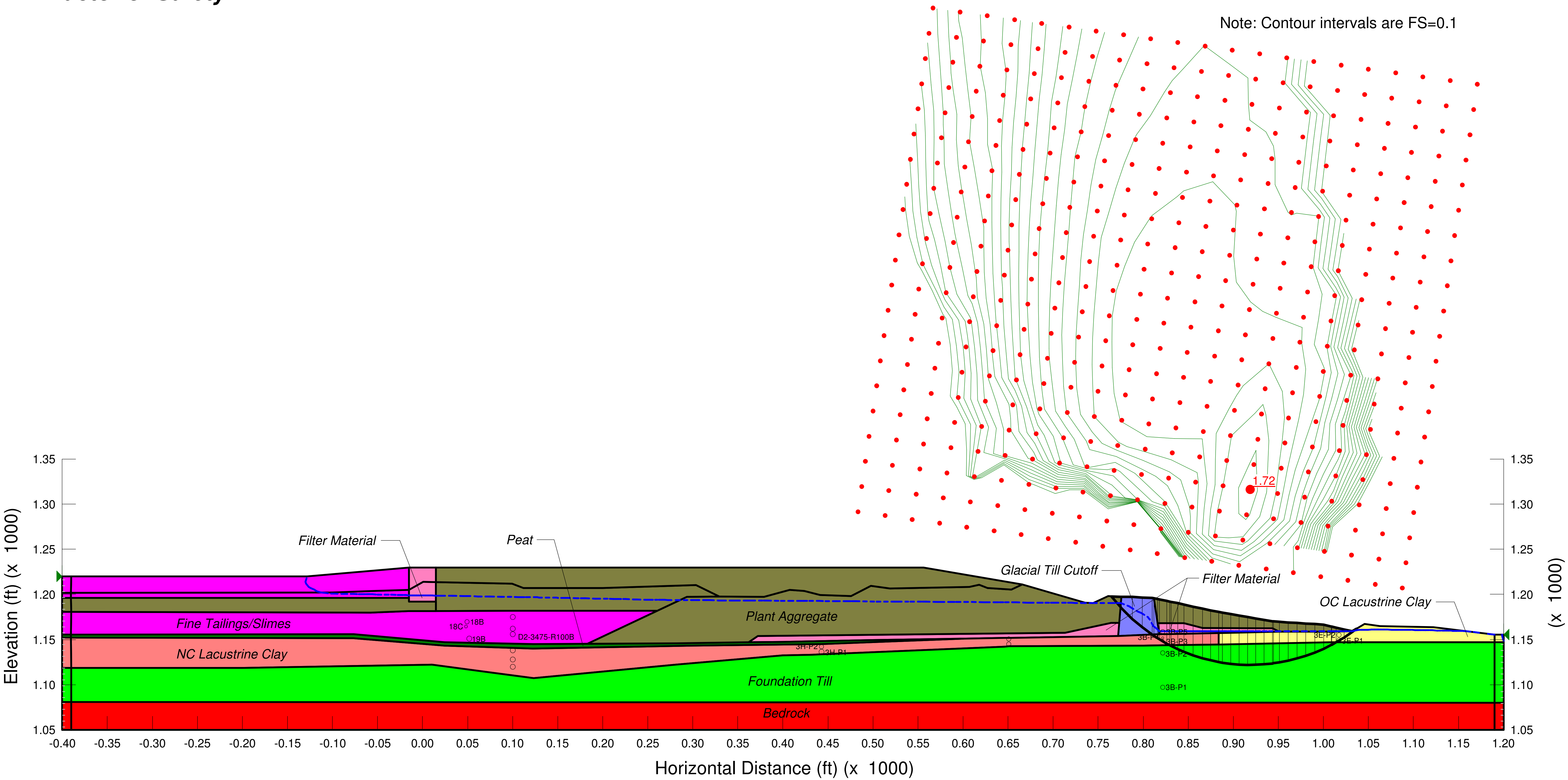


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Existing Geometry (El. 1215), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D2_S3475_E1215_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.29

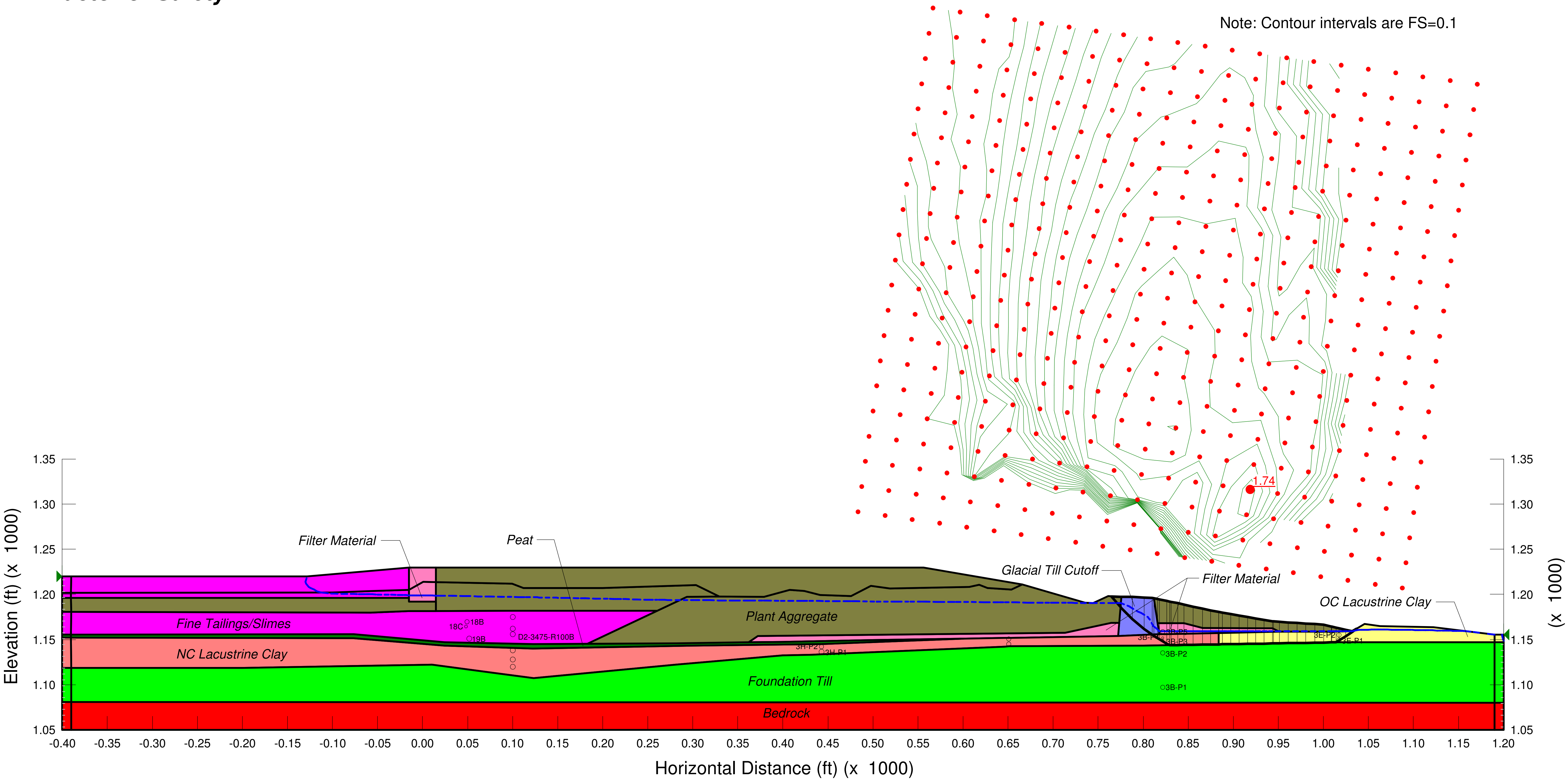


Proposed Geometry El. 1,230 feet

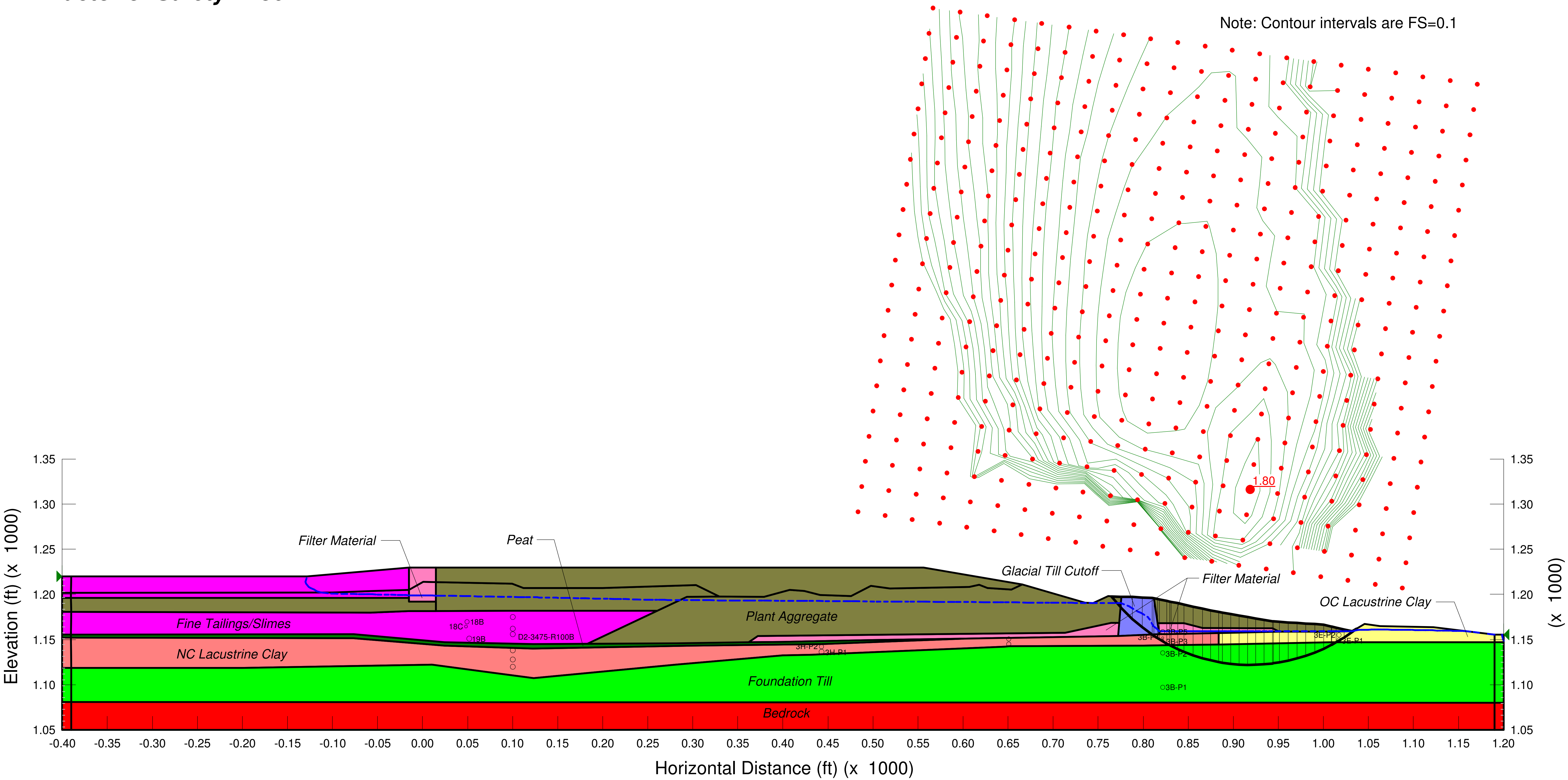
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D2_S3475_E1230_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.72



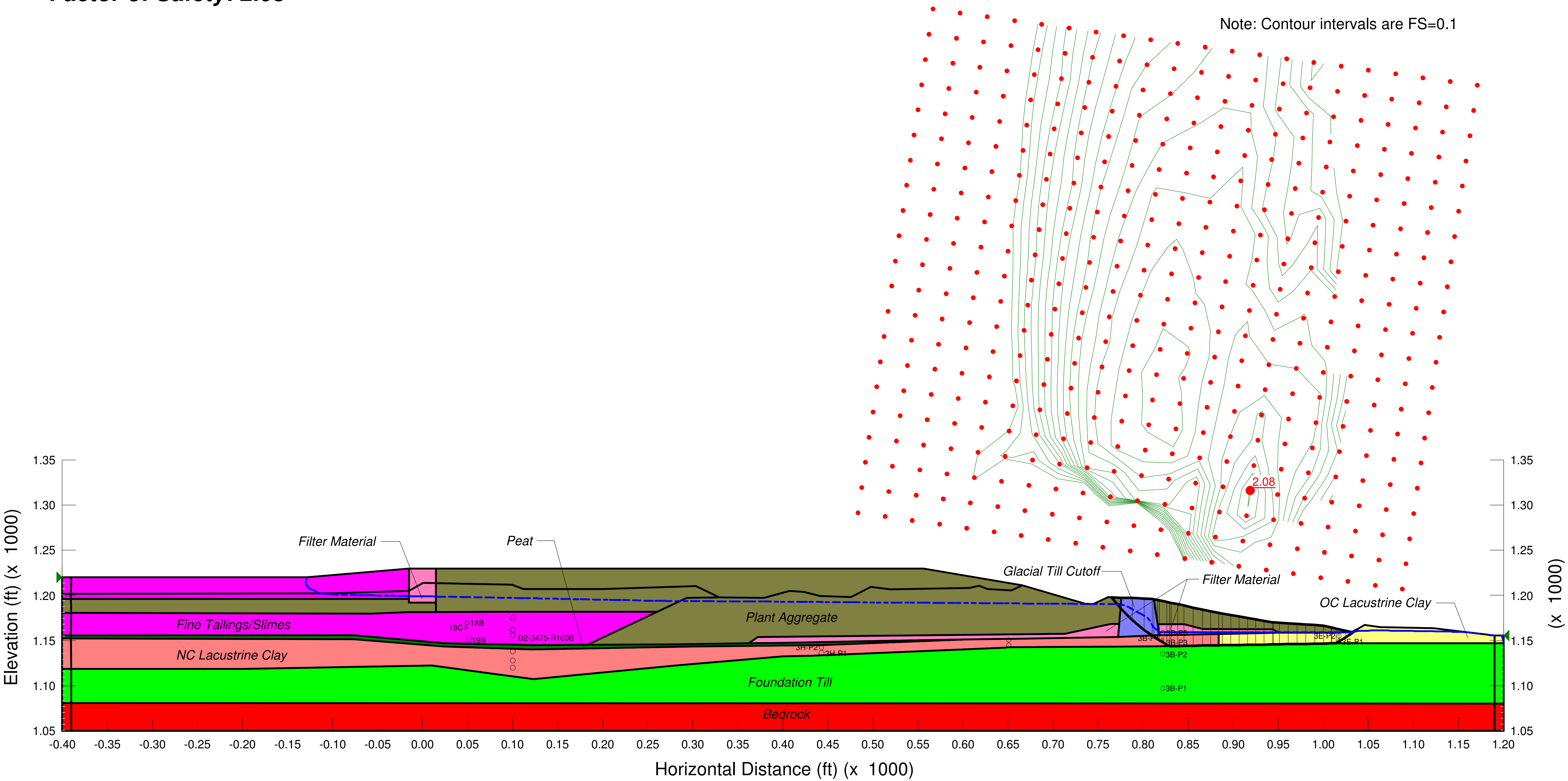
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D2_S3475_E1230_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.74



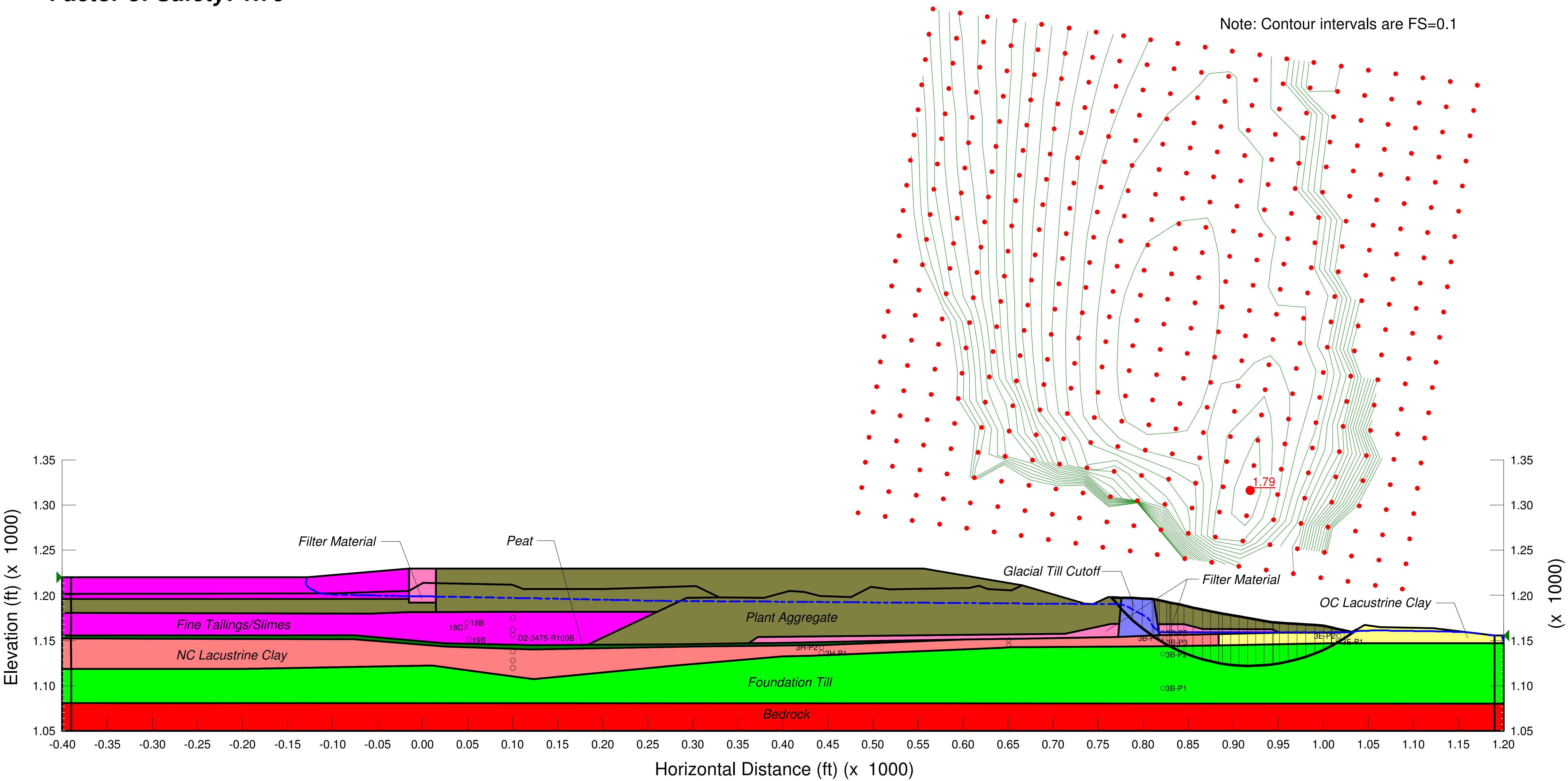
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D2_S3475_E1230_USSA_LC6_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.80



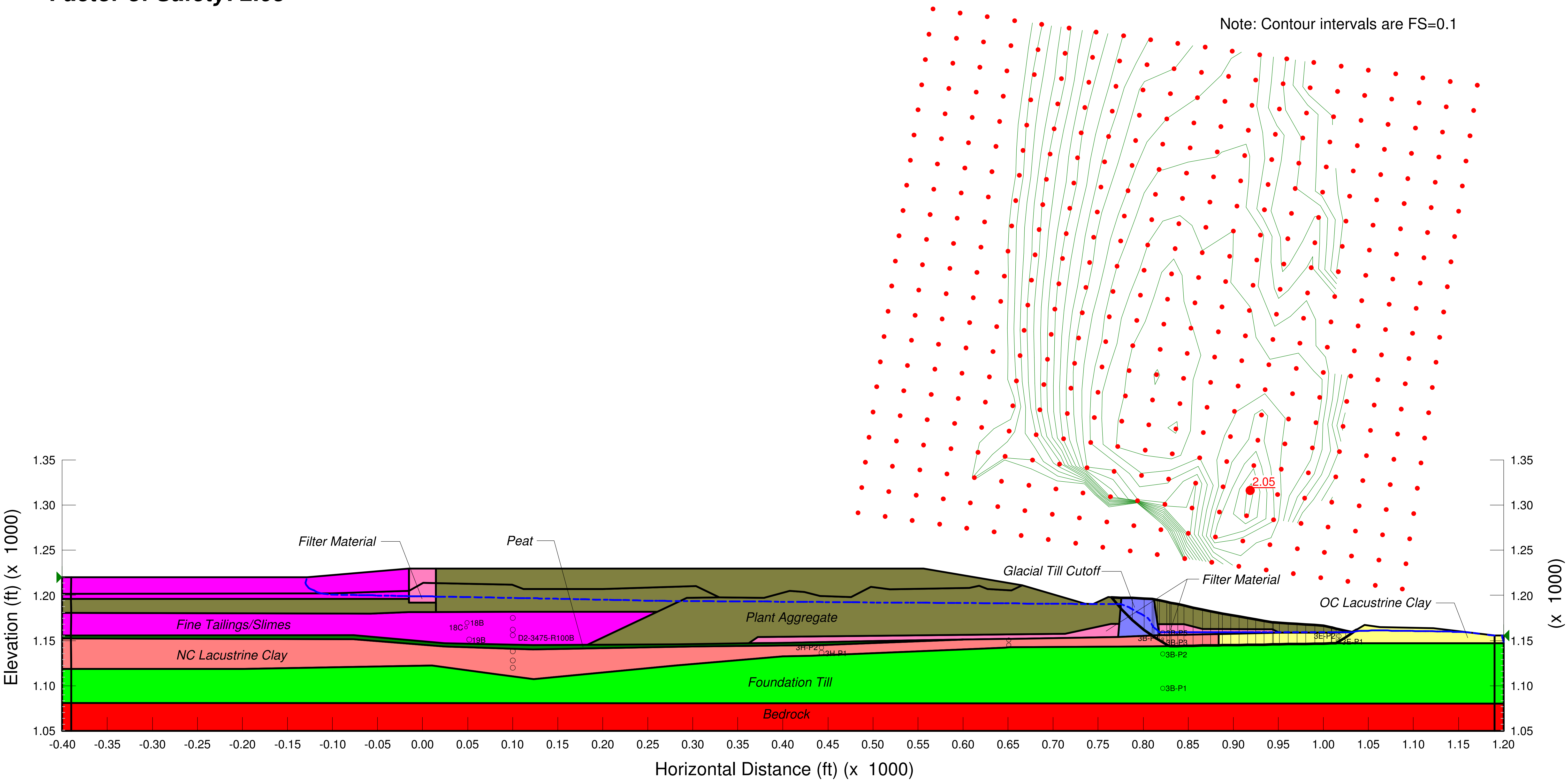
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.2, FM Block
File Name: D2_S3475_E1230_USSA_LC6_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.08



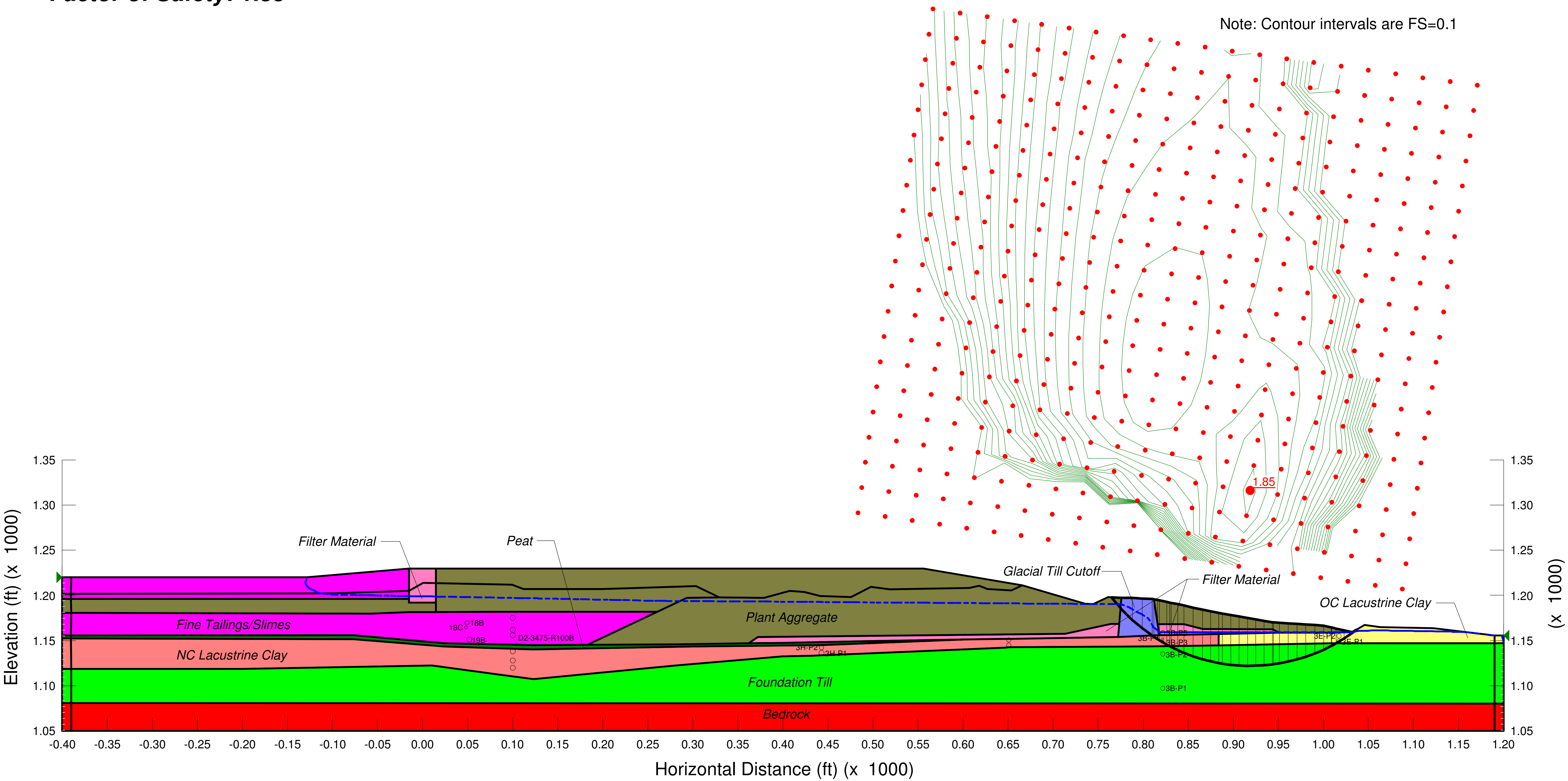
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.2, FM Toe
File Name: D2_S3475_E1230_USSA_LC7_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.79



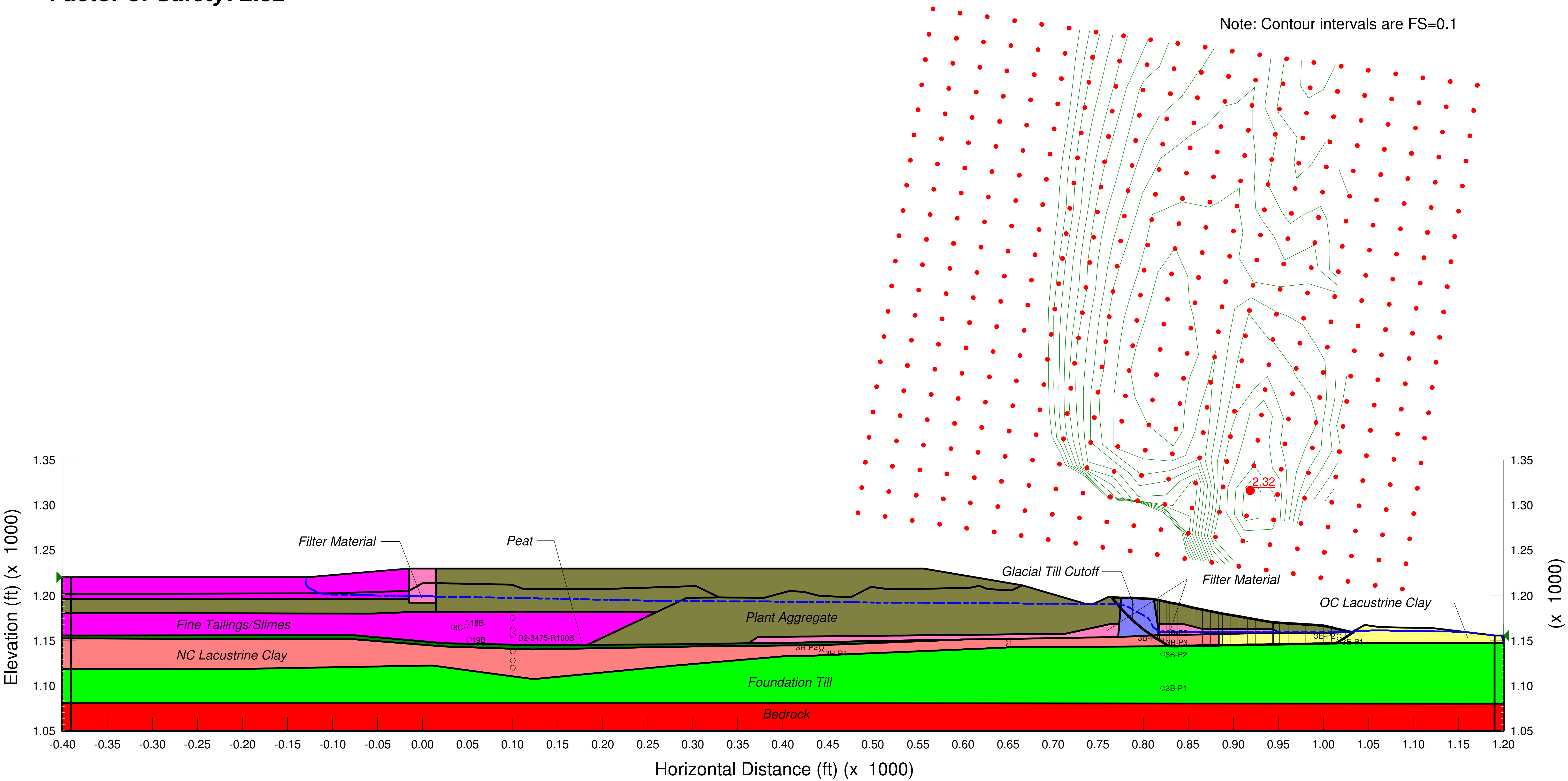
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.2, FM Block
File Name: D2_S3475_E1230_USSA_LC7_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.05



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D2_S3475_E1230_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.85



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D2_S3475_E1230_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.32



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Toe
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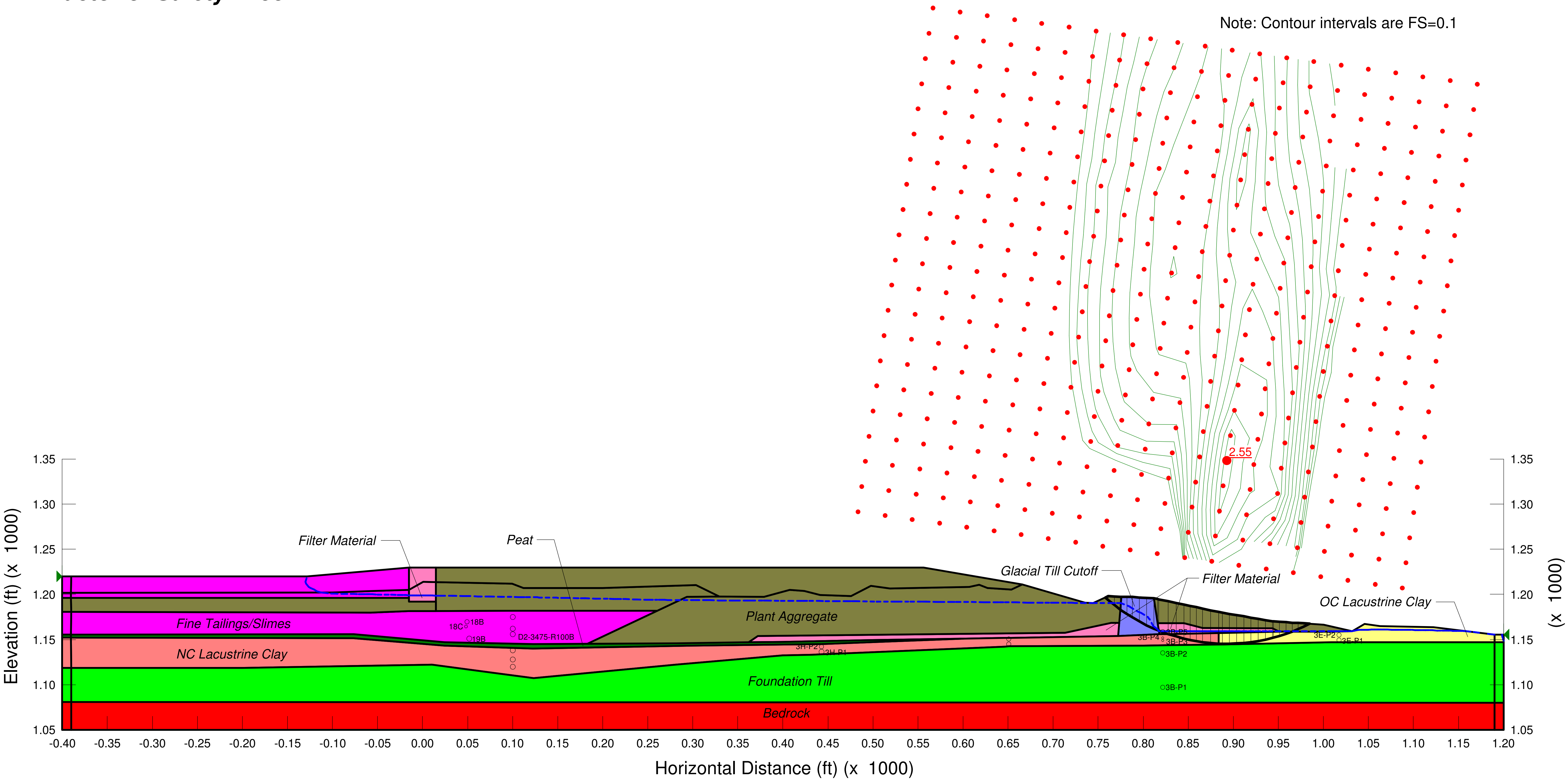
Last Saved Date: 11/17/2008
Factor of Safety: 2.55



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Block
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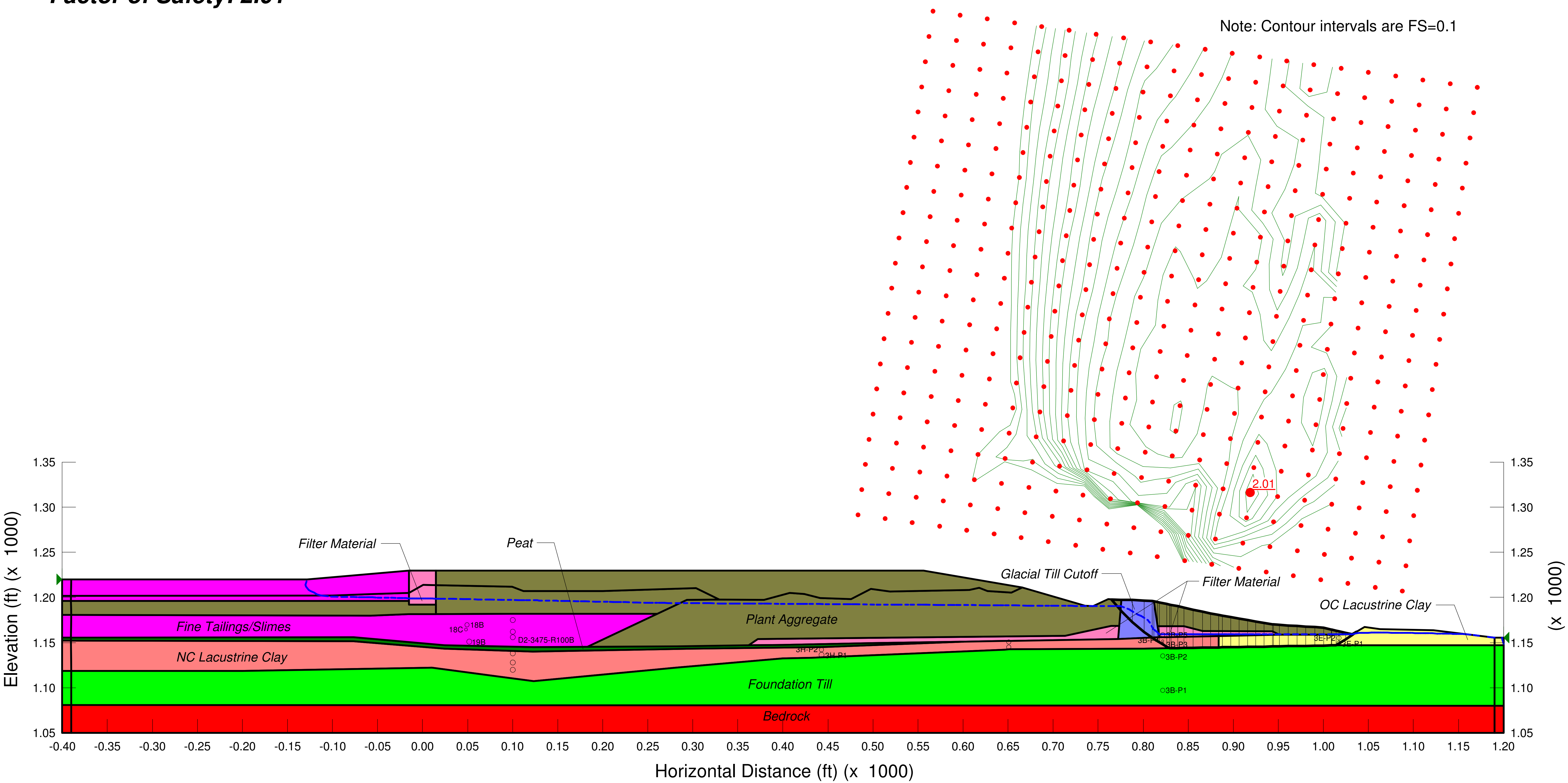
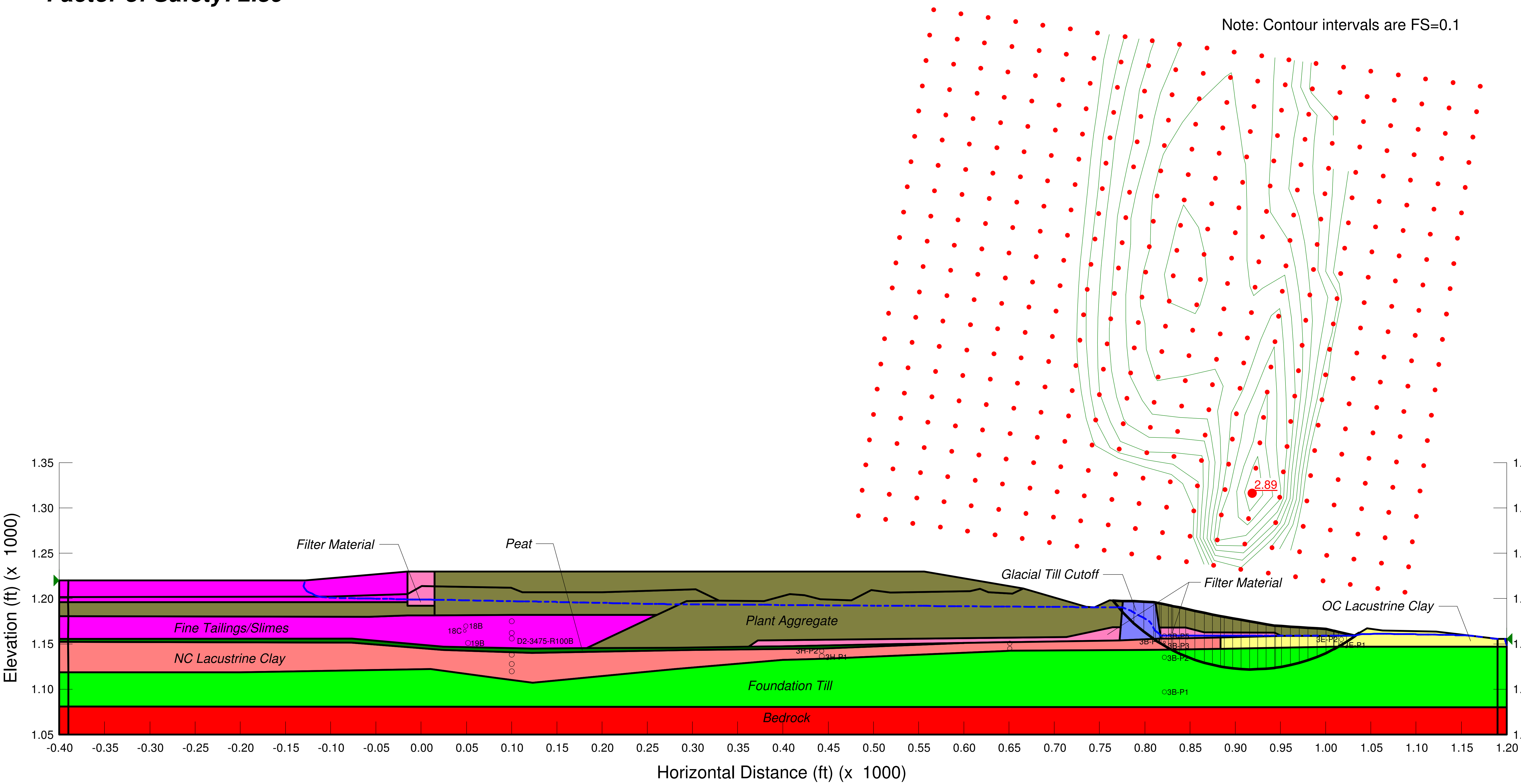
Last Saved Date: 11/17/2008
Factor of Safety: 2.01



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Toe
File Name: D2_S3475_E1230_ESSA_LC2_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.89



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Block
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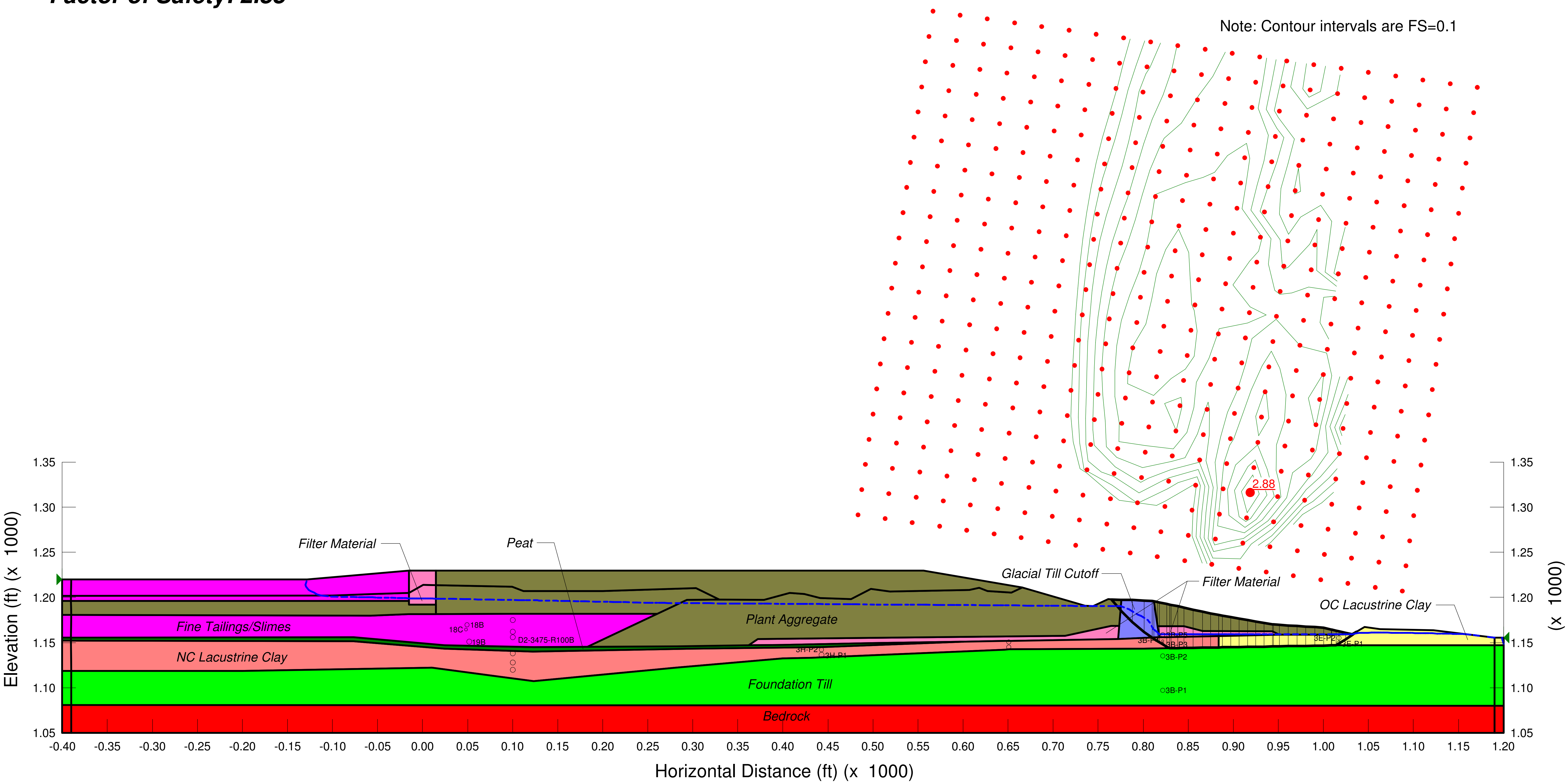
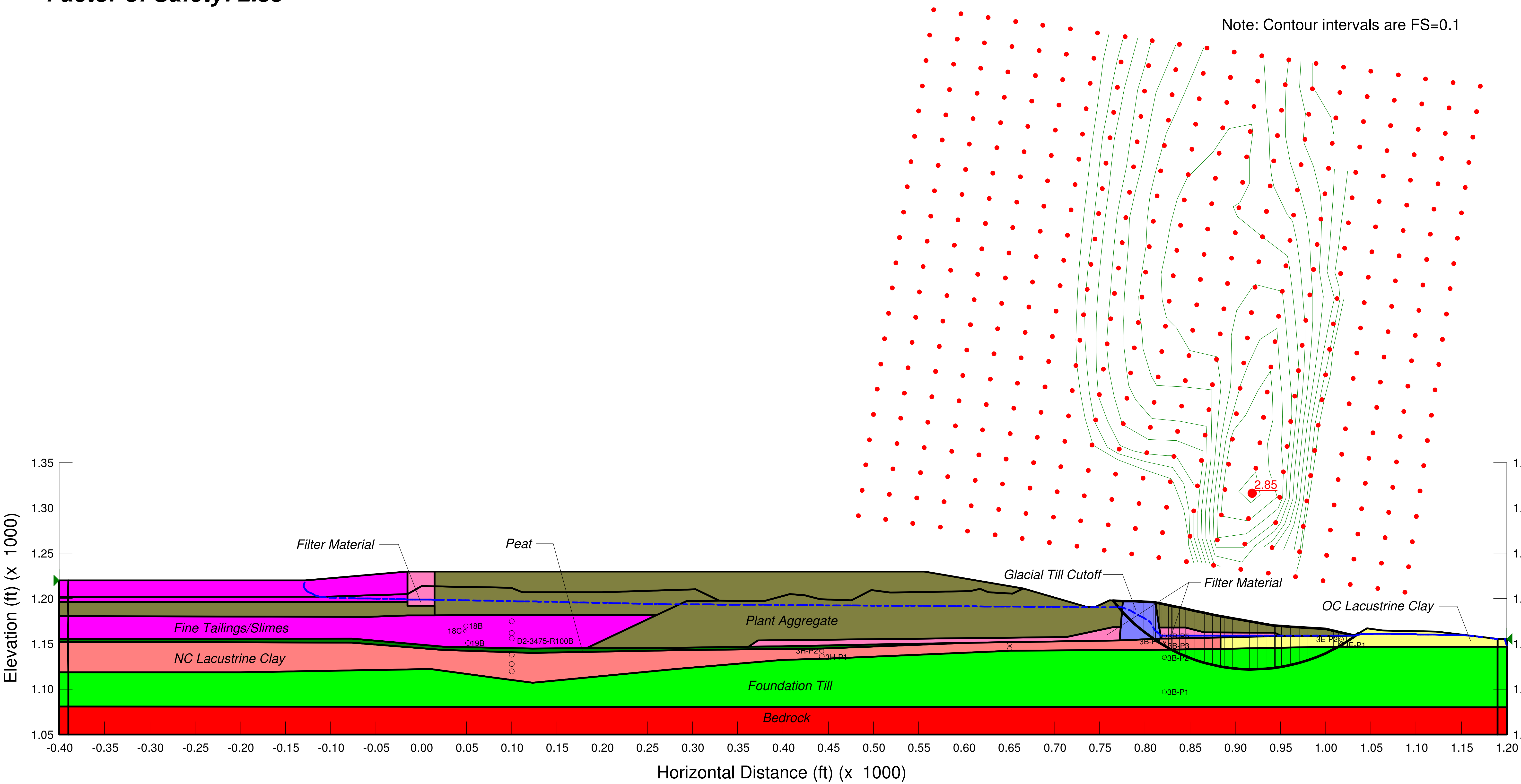
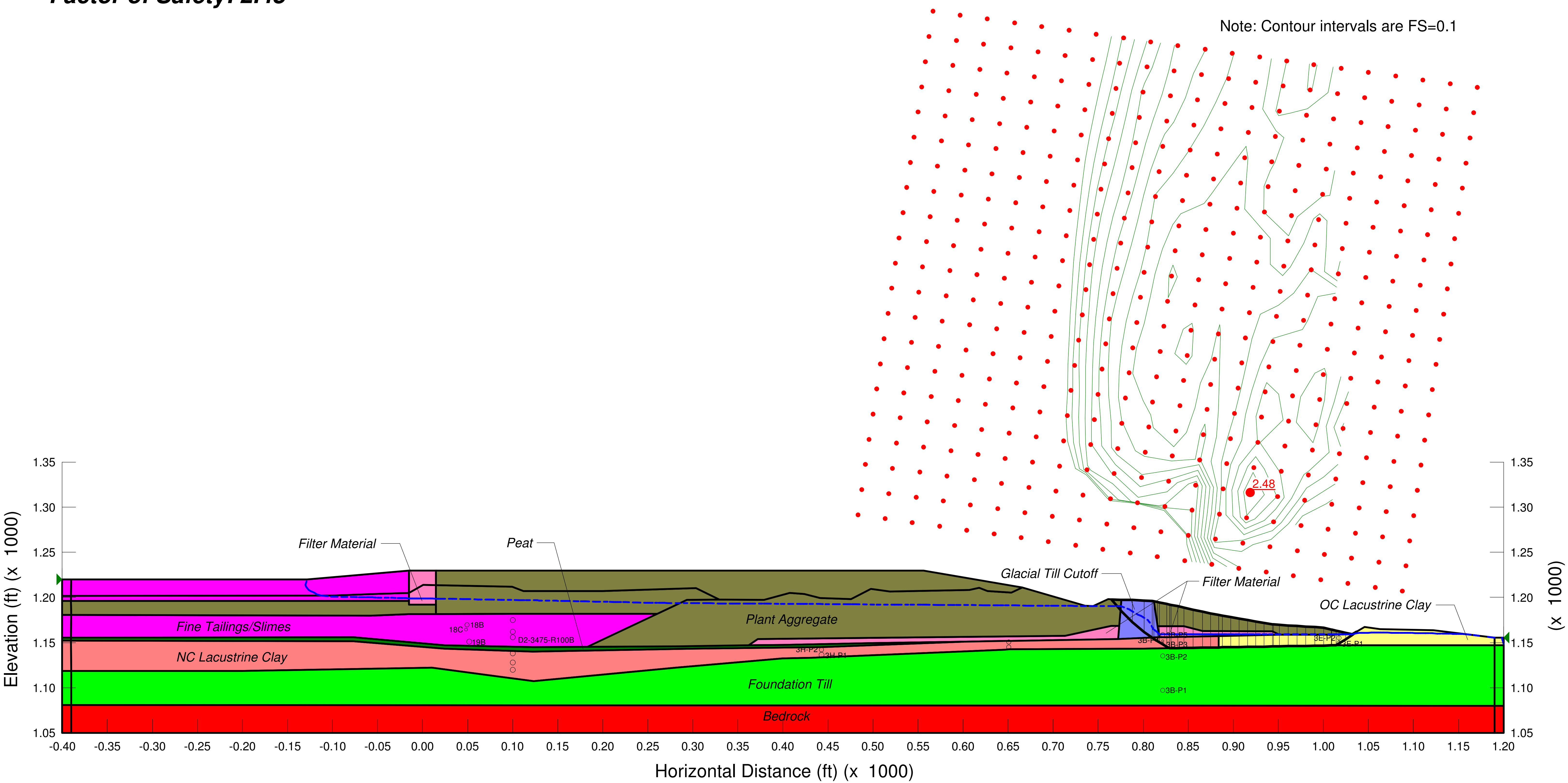
Last Saved Date: 11/17/2008
Factor of Safety: 2.88



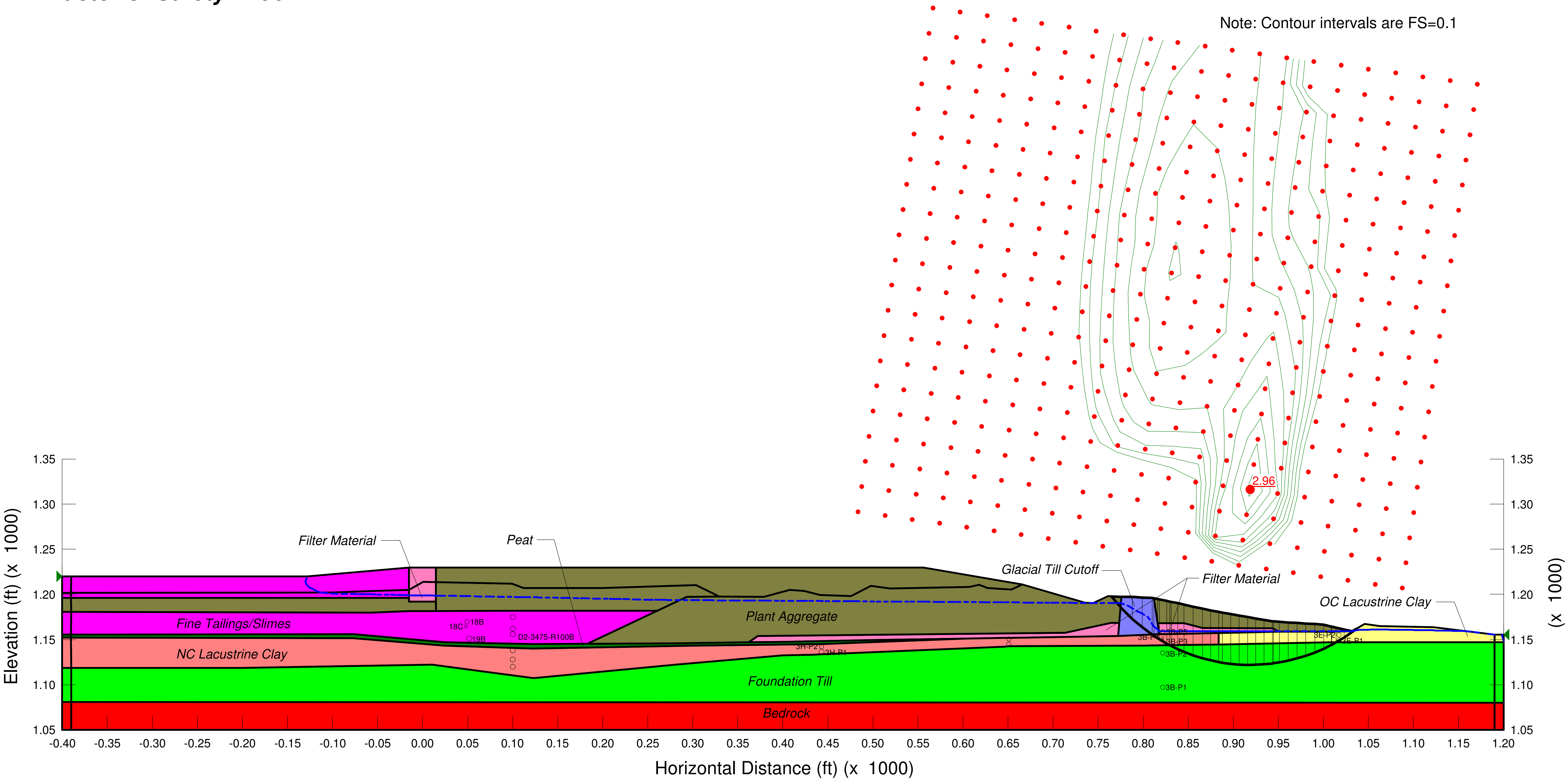
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Toe
File Name: D2_S3475_E1230_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.85



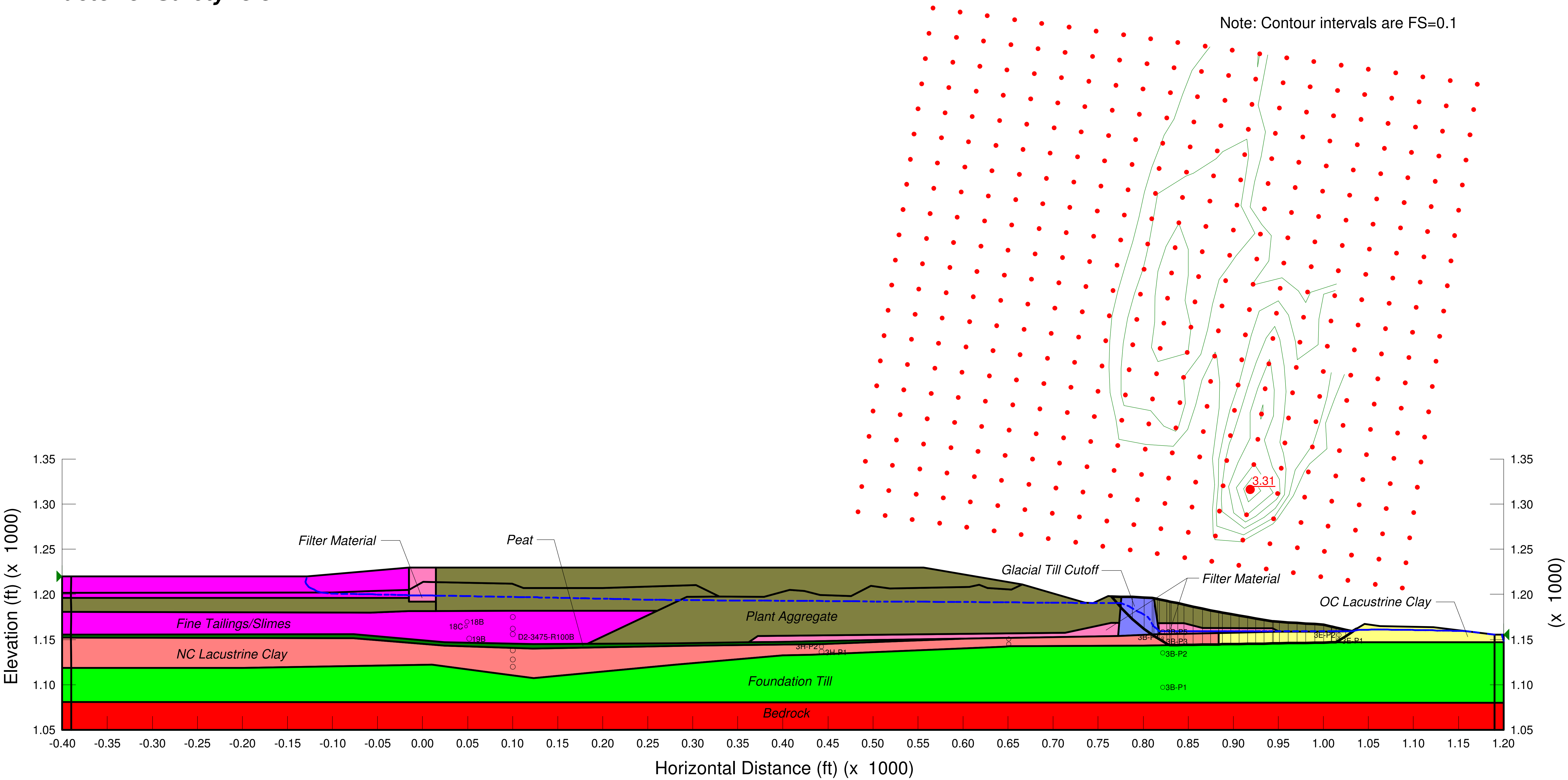
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Block
File Name: D2_S3475_E1230_ESSA_LC3_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.48



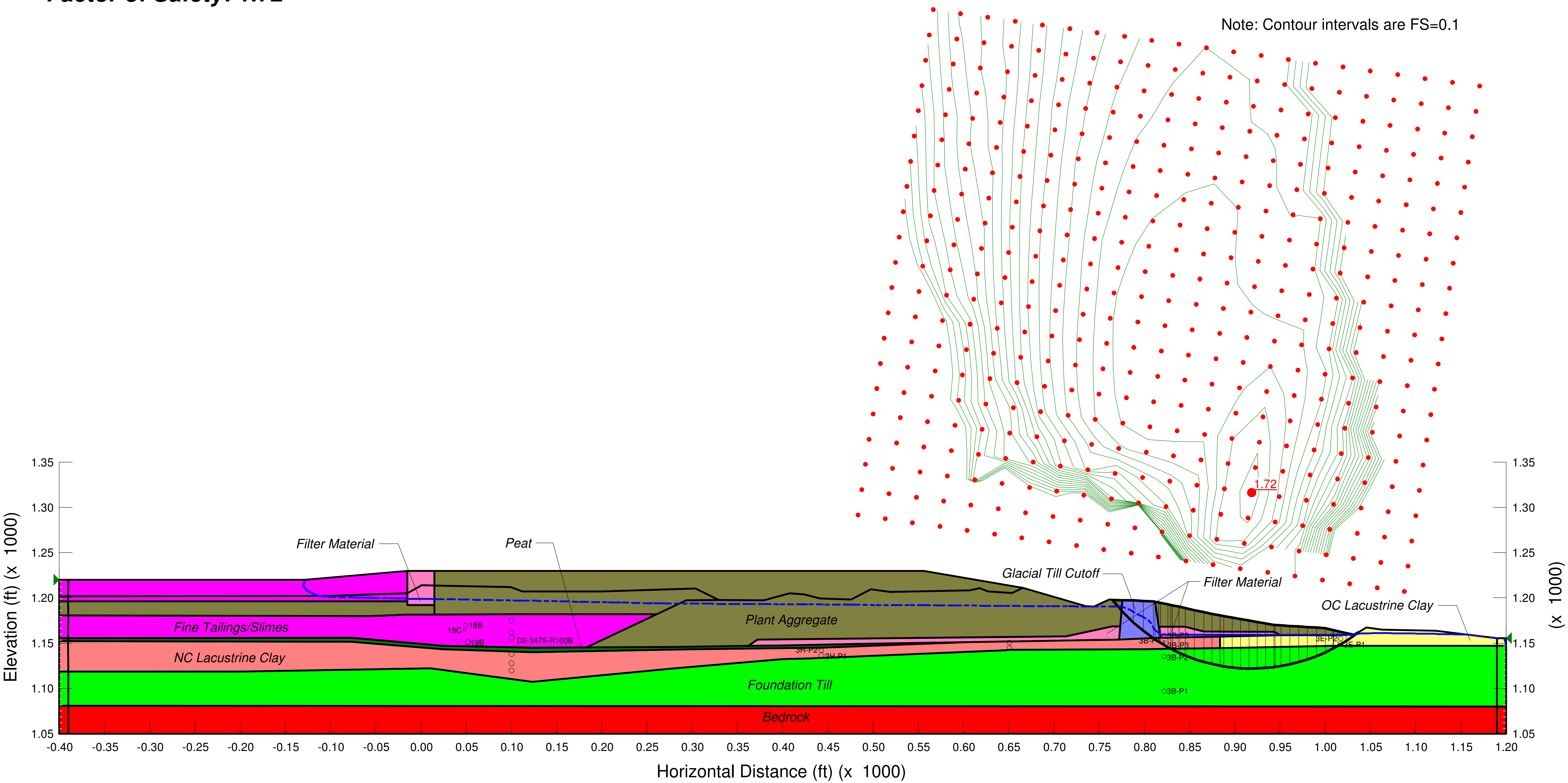
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Toe
File Name: D2_S3475_E1230_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.96



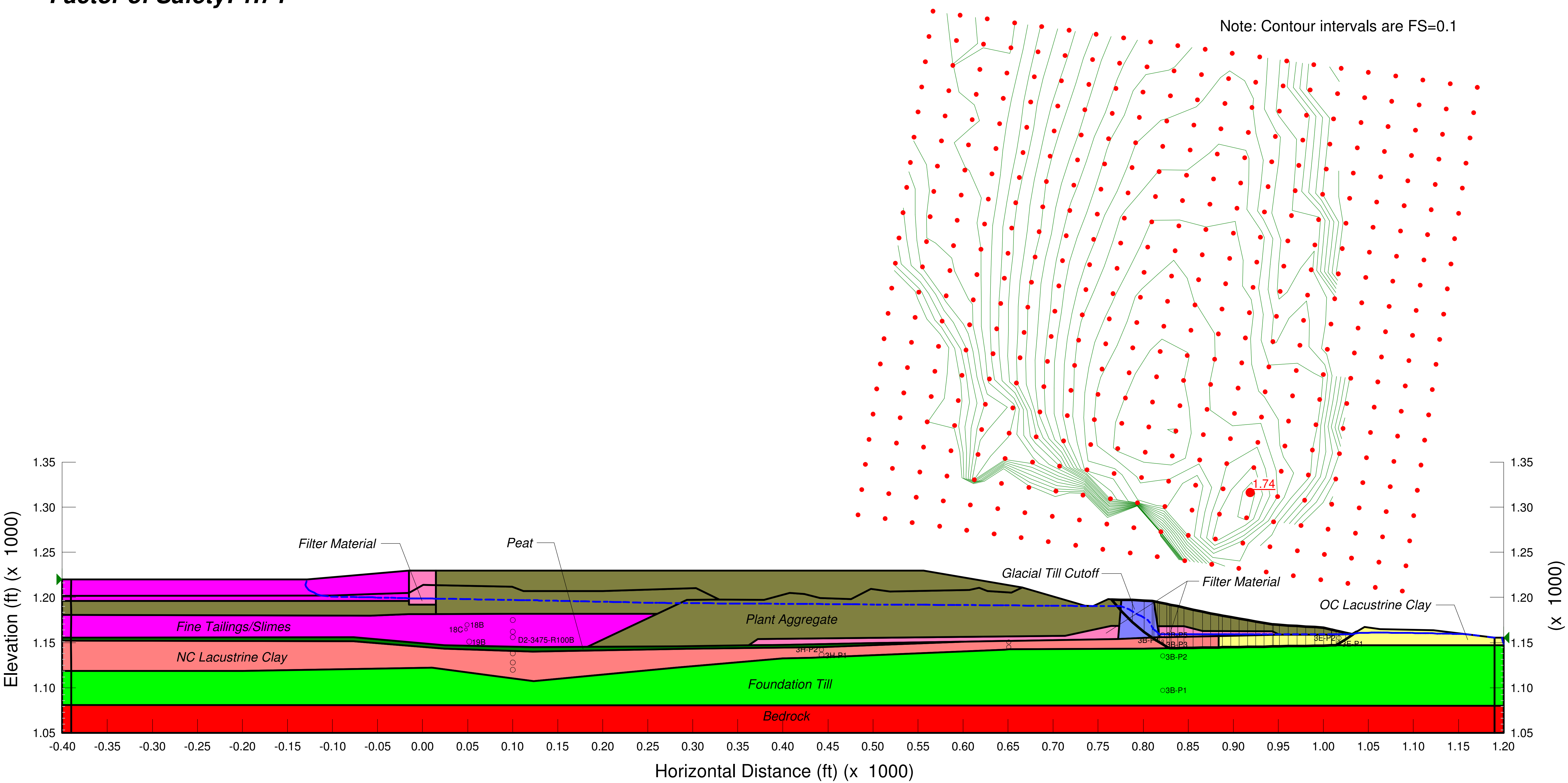
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Block
File Name: D2_S3475_E1230_ESSA_LC4_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 3.31



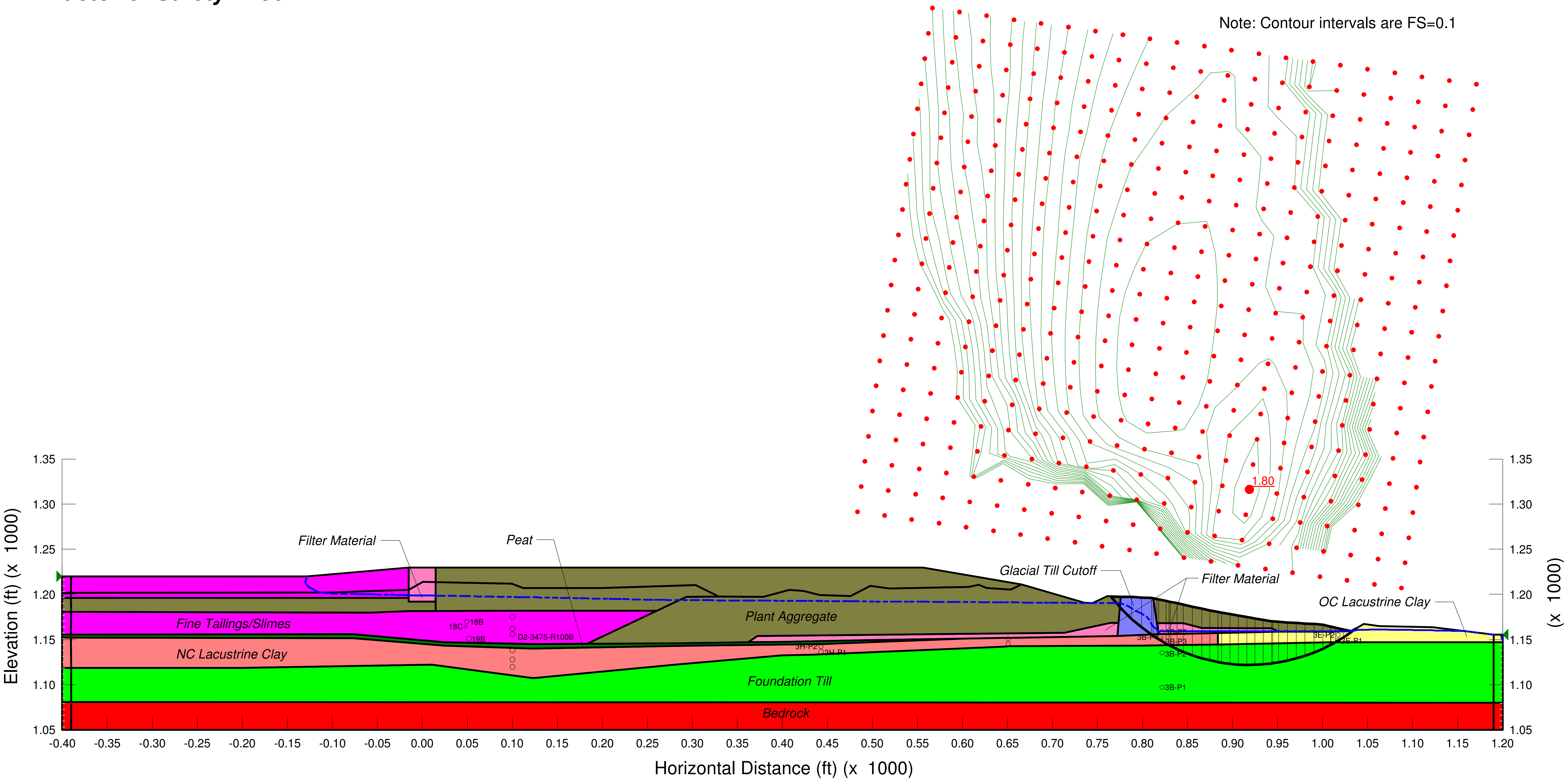
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D2_S3475_E1230_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.72



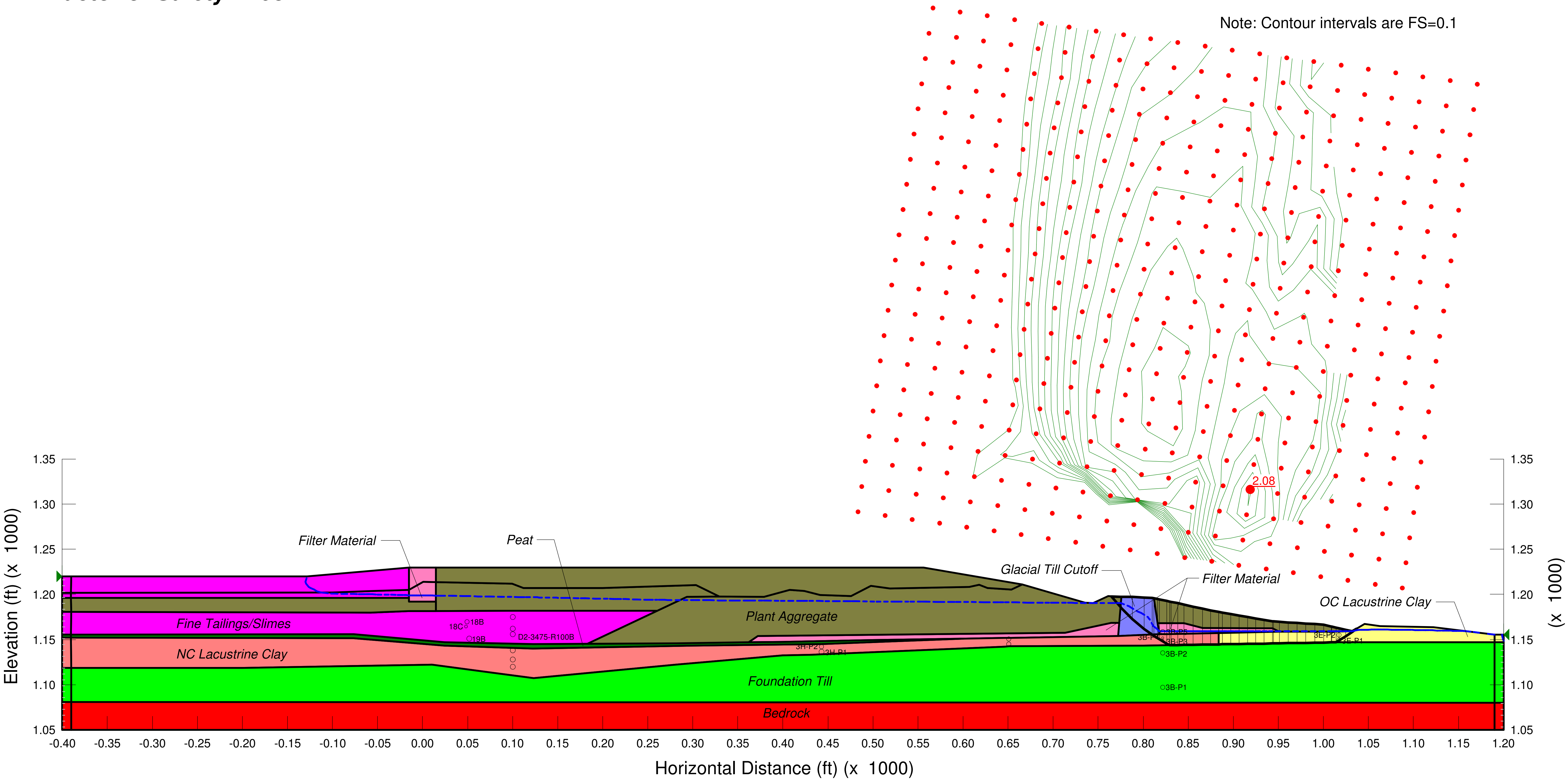
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D2_S3475_E1230_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.74



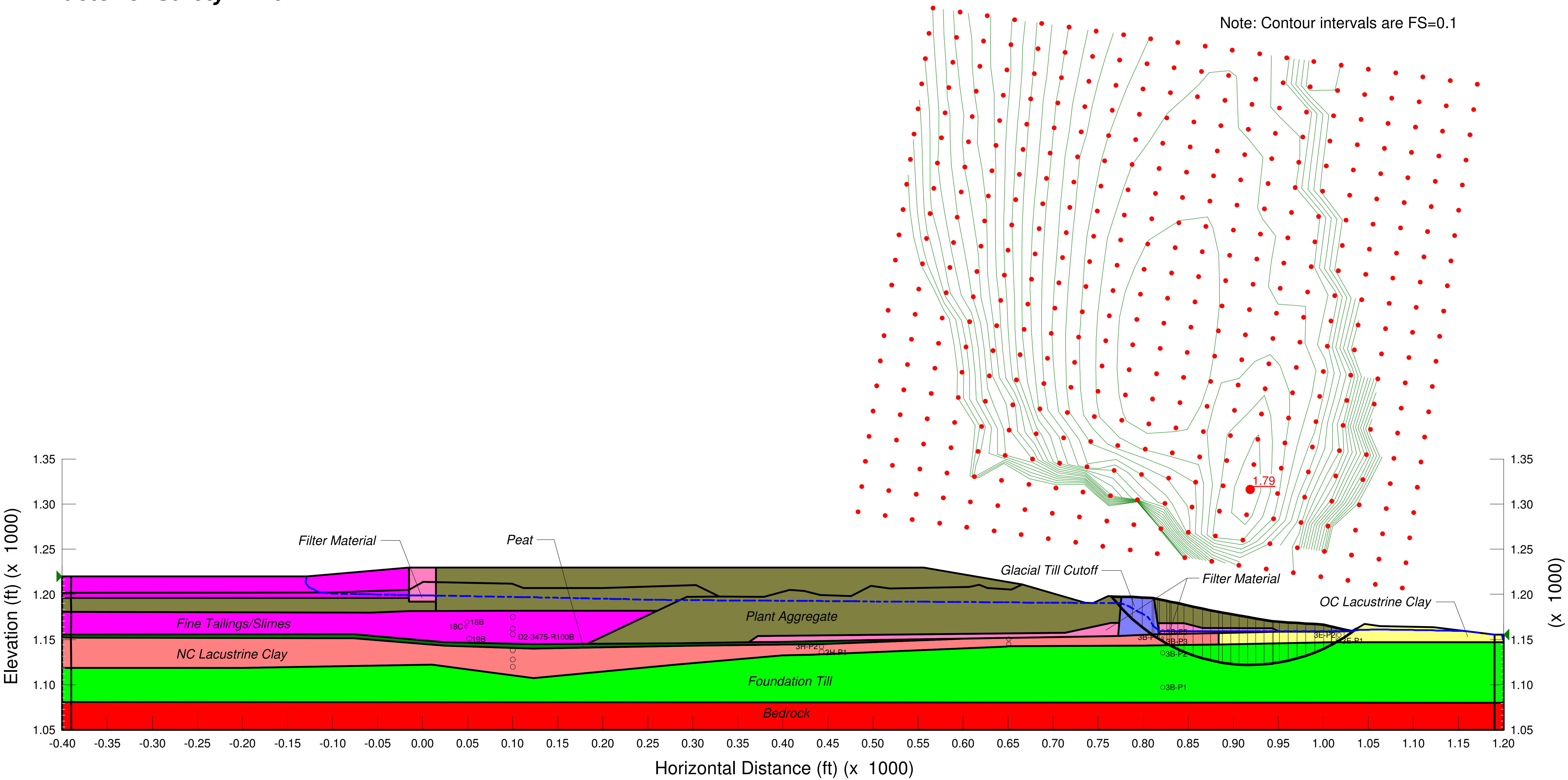
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D2_S3475_E1230_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.80



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D2_S3475_E1230_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.08



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D2_S3475_E1230_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.79



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FT 0.1, FM Block
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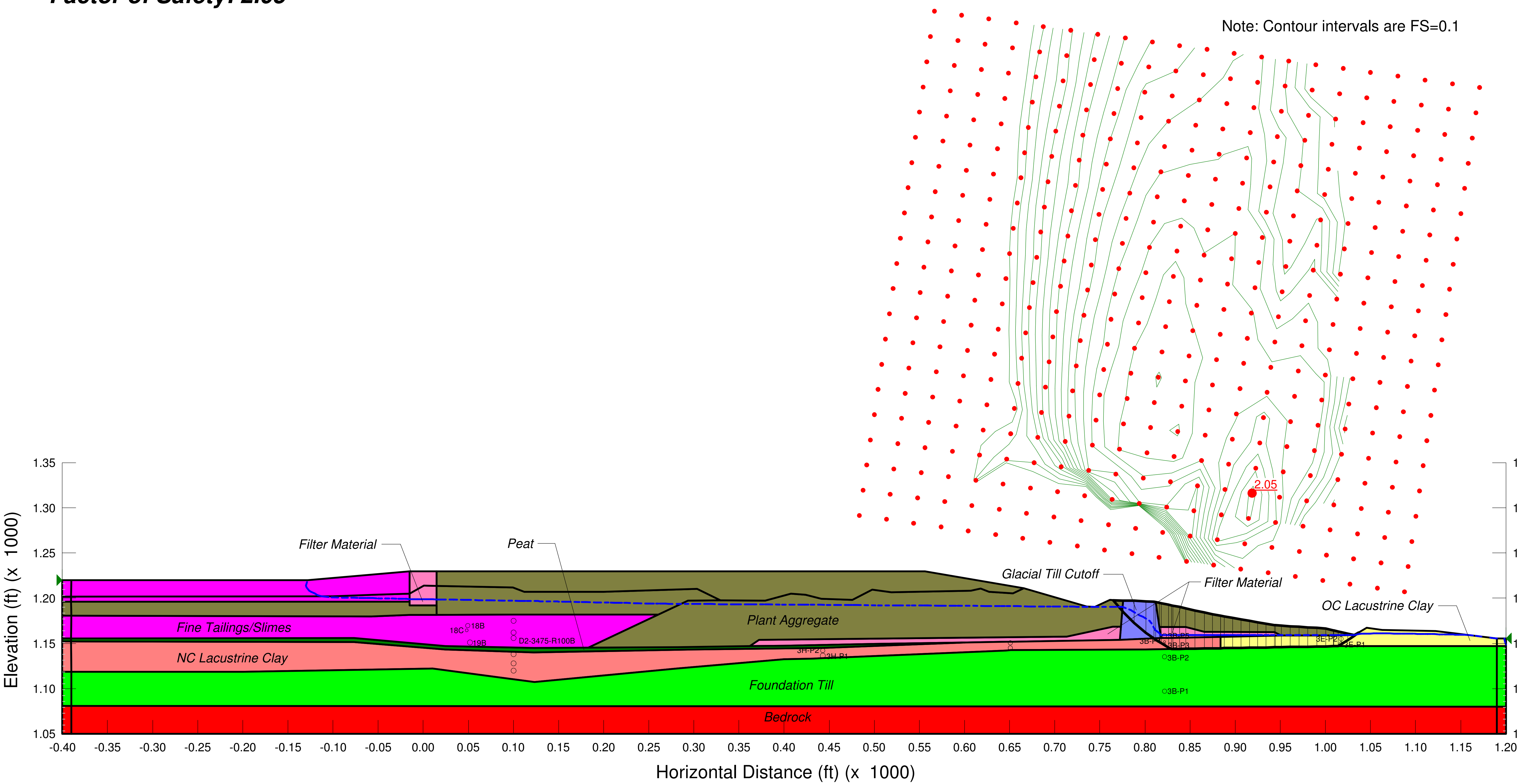
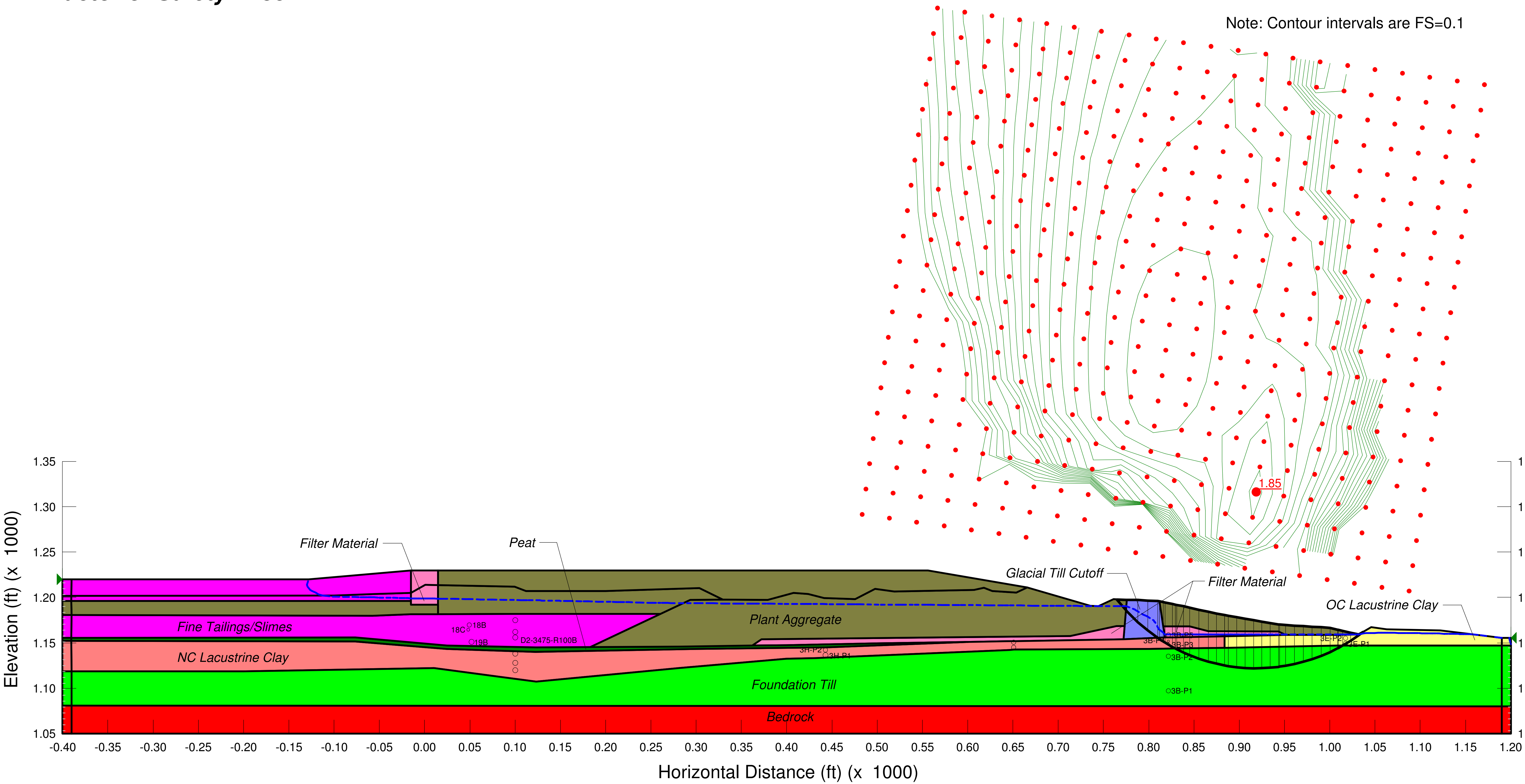
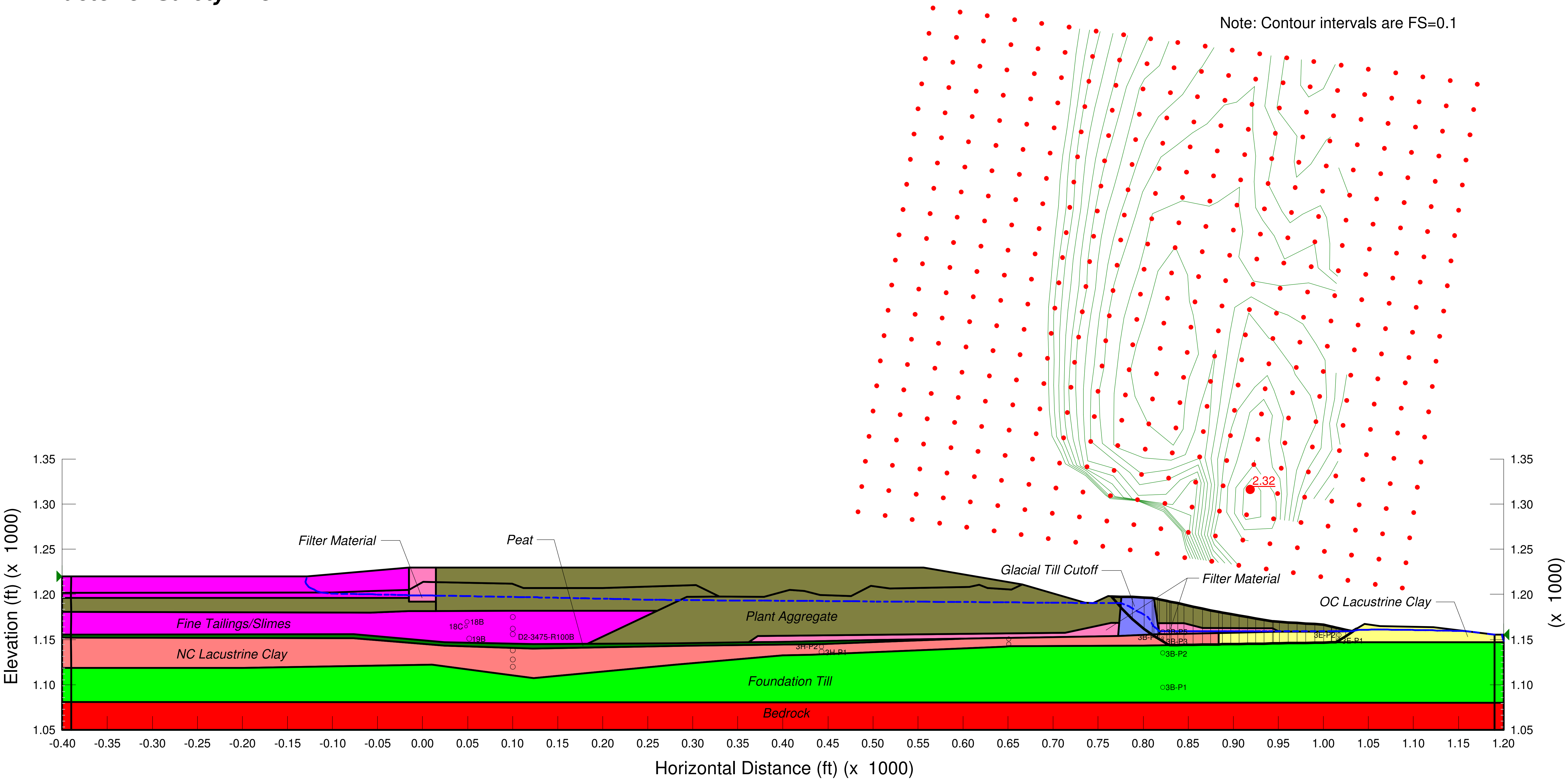
Last Saved Date: 11/17/2008
Factor of Safety: 2.05



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D2_S3475_E1230_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.85

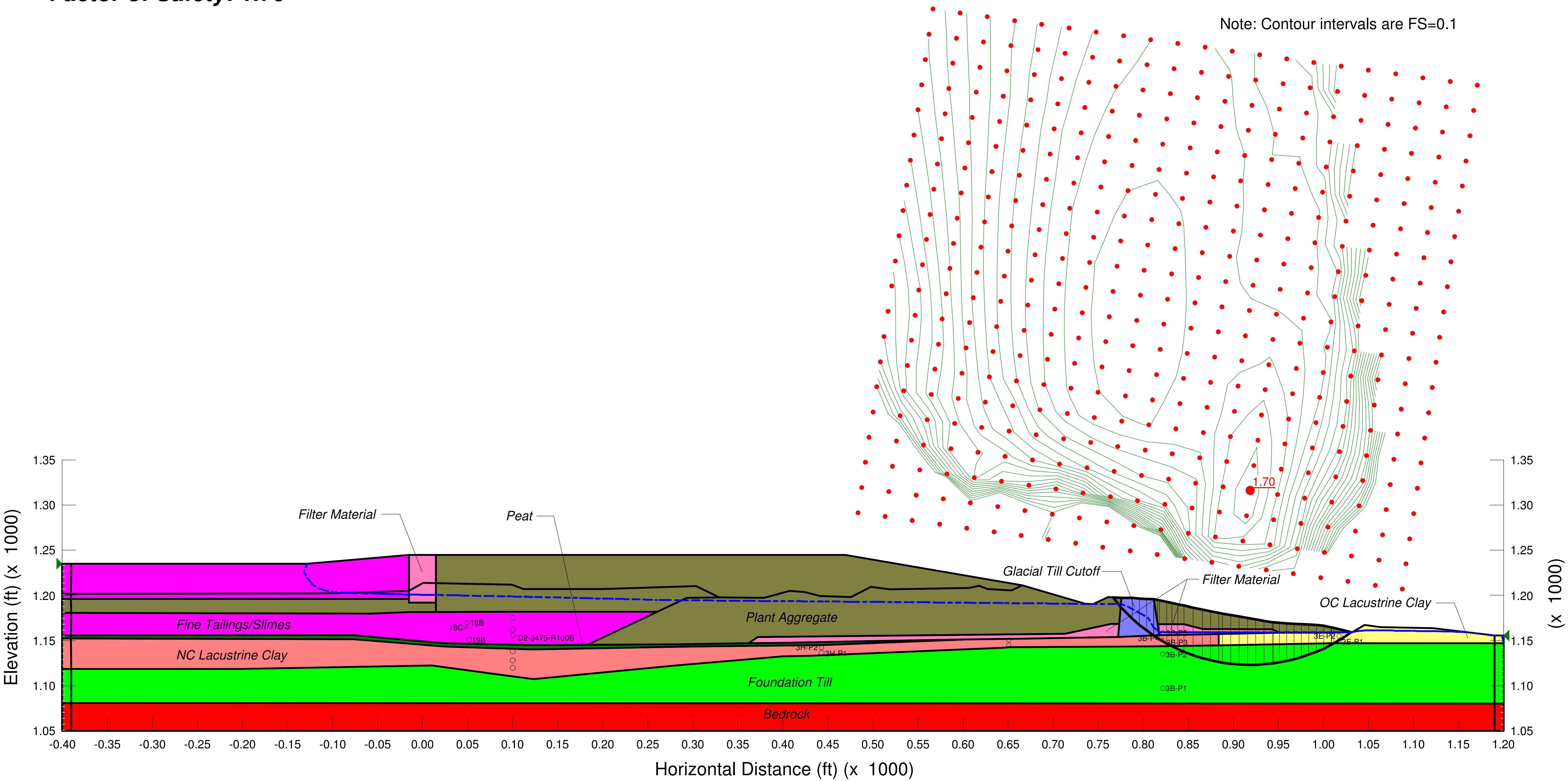


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D2_S3475_E1230_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.32

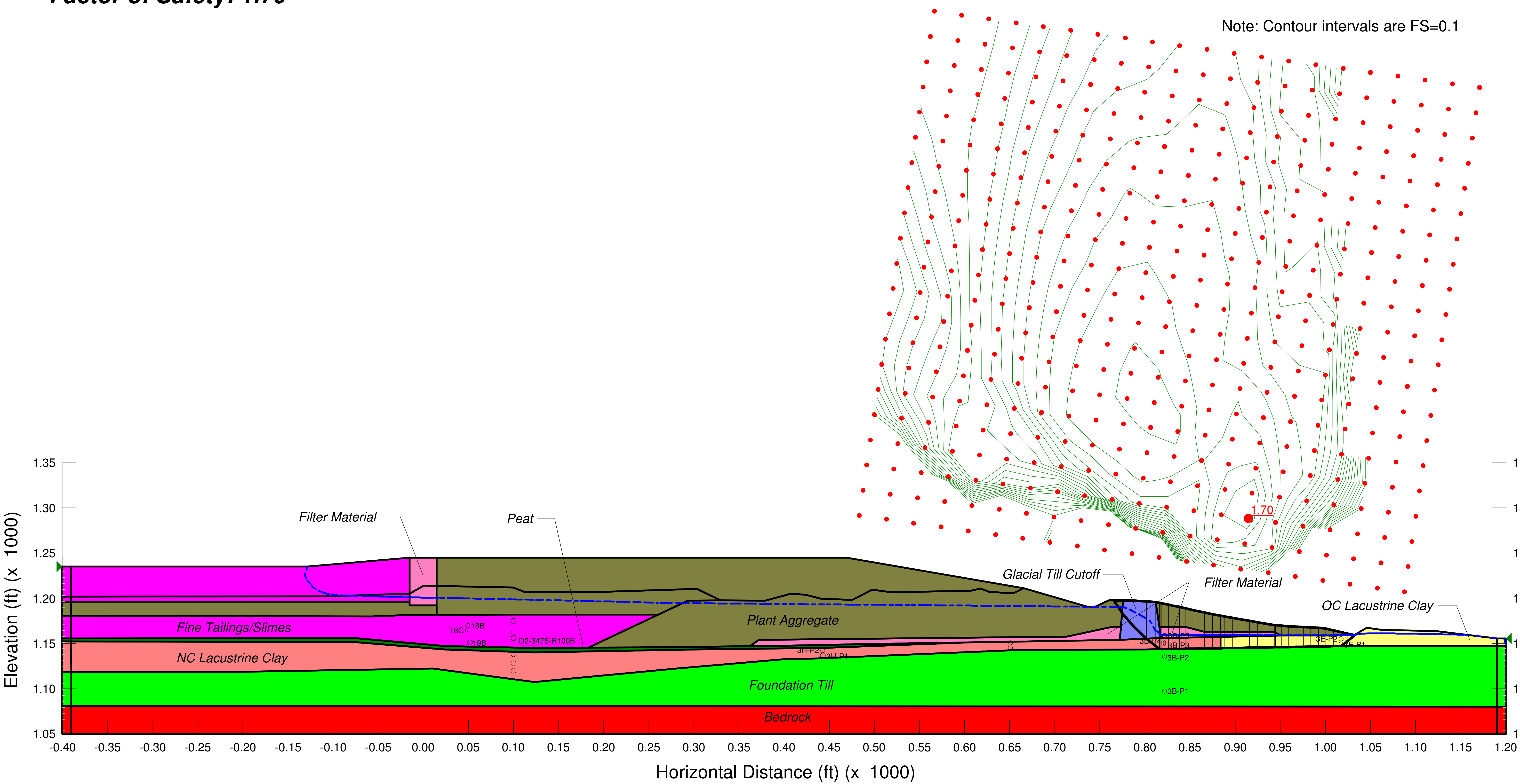


Proposed Geometry El. 1,245 feet

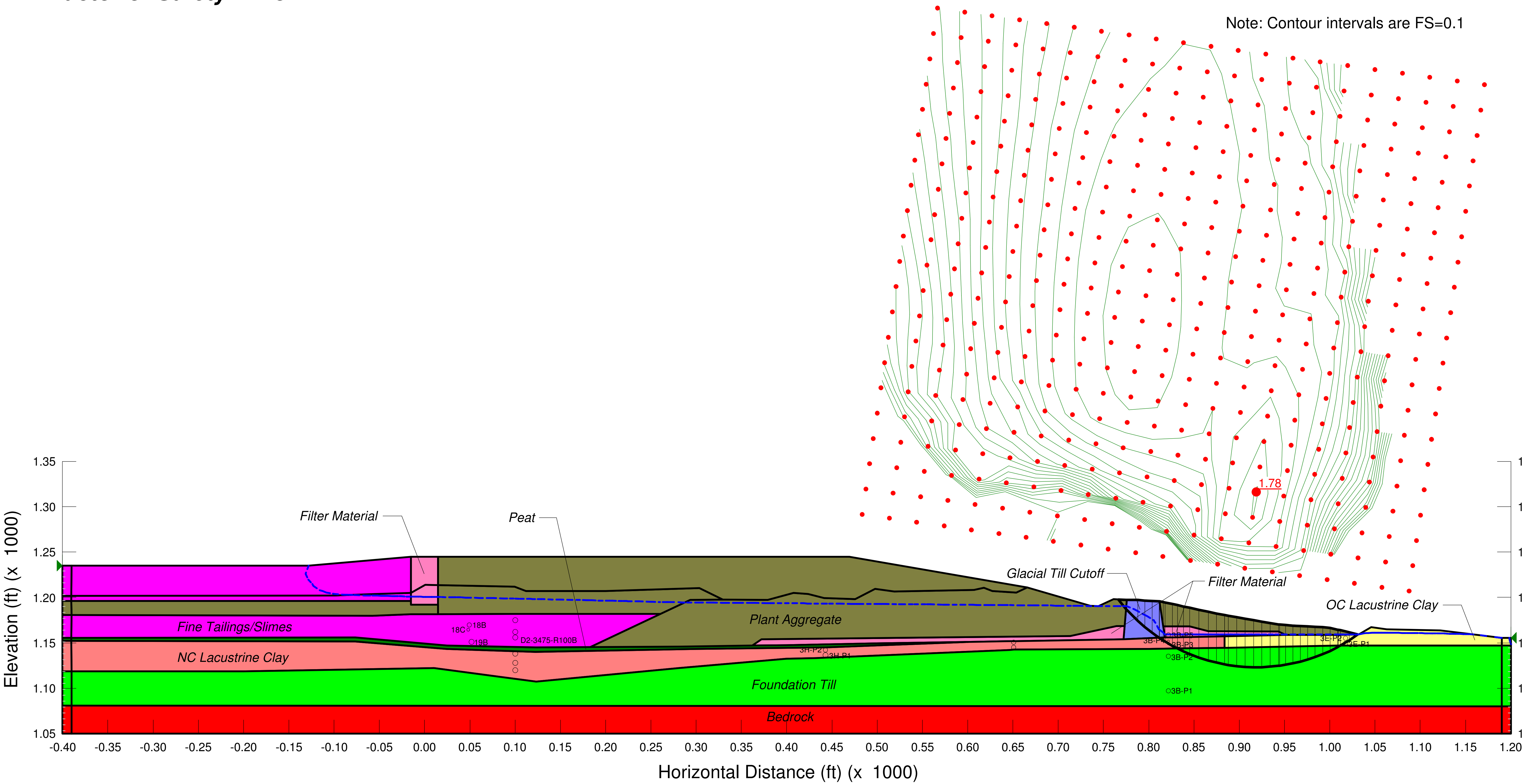
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D2_S3475_E1245_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.70



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D2_S3475_E1245_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.70



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.2, FM Toe
_File Name: D2_S3475_E1245_USSA_LC6_FT2_FM1.gsz_
Last Saved Date: 6/19/2009
Factor of Safety: 1.78



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.2, FM Block
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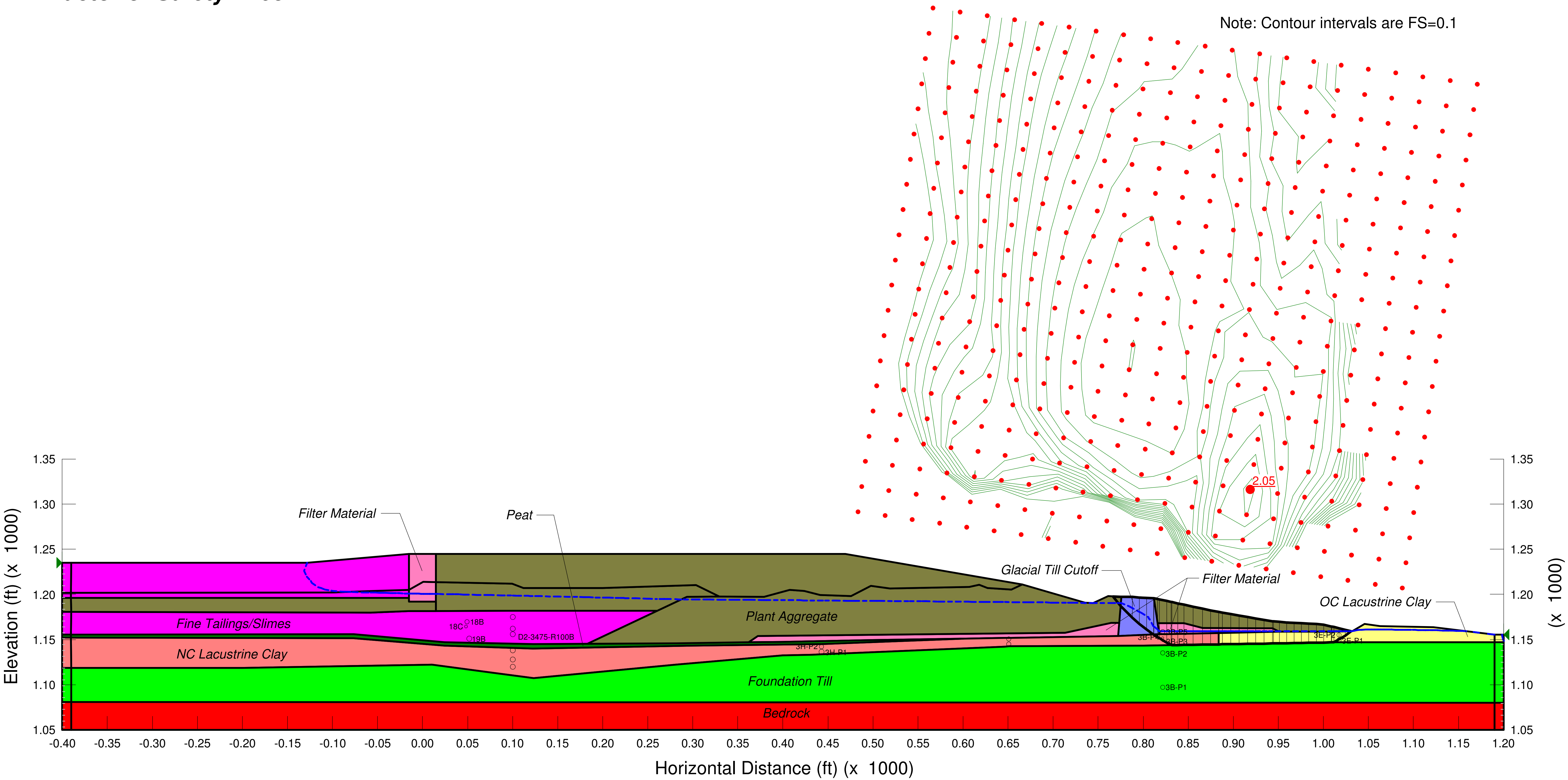
Last Saved Date: 6/19/2009
Factor of Safety: 2.05



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.2, FM Toe
File Name: D2_S3475_E1245_USSA_LC7_FT2_FM1.gsz
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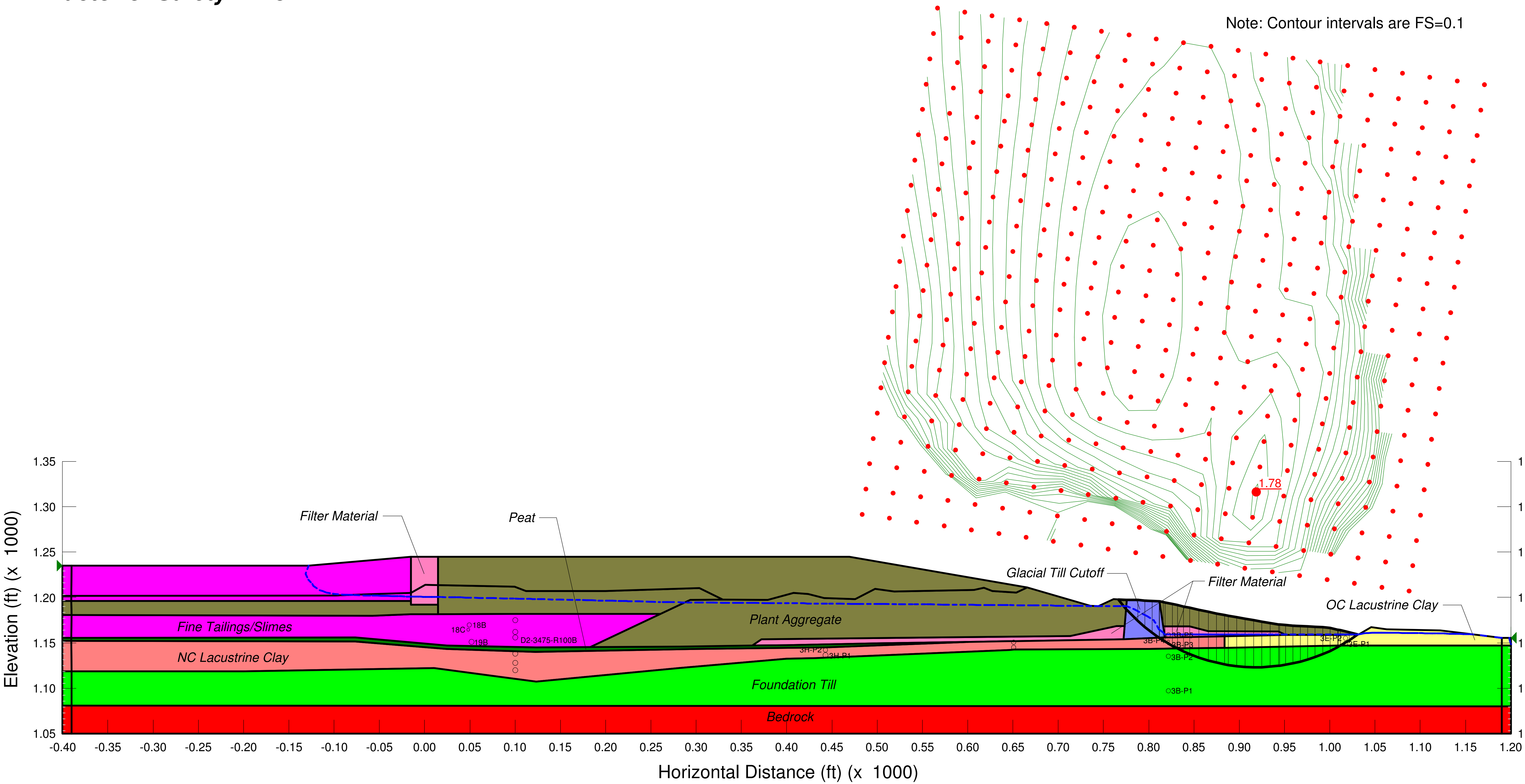
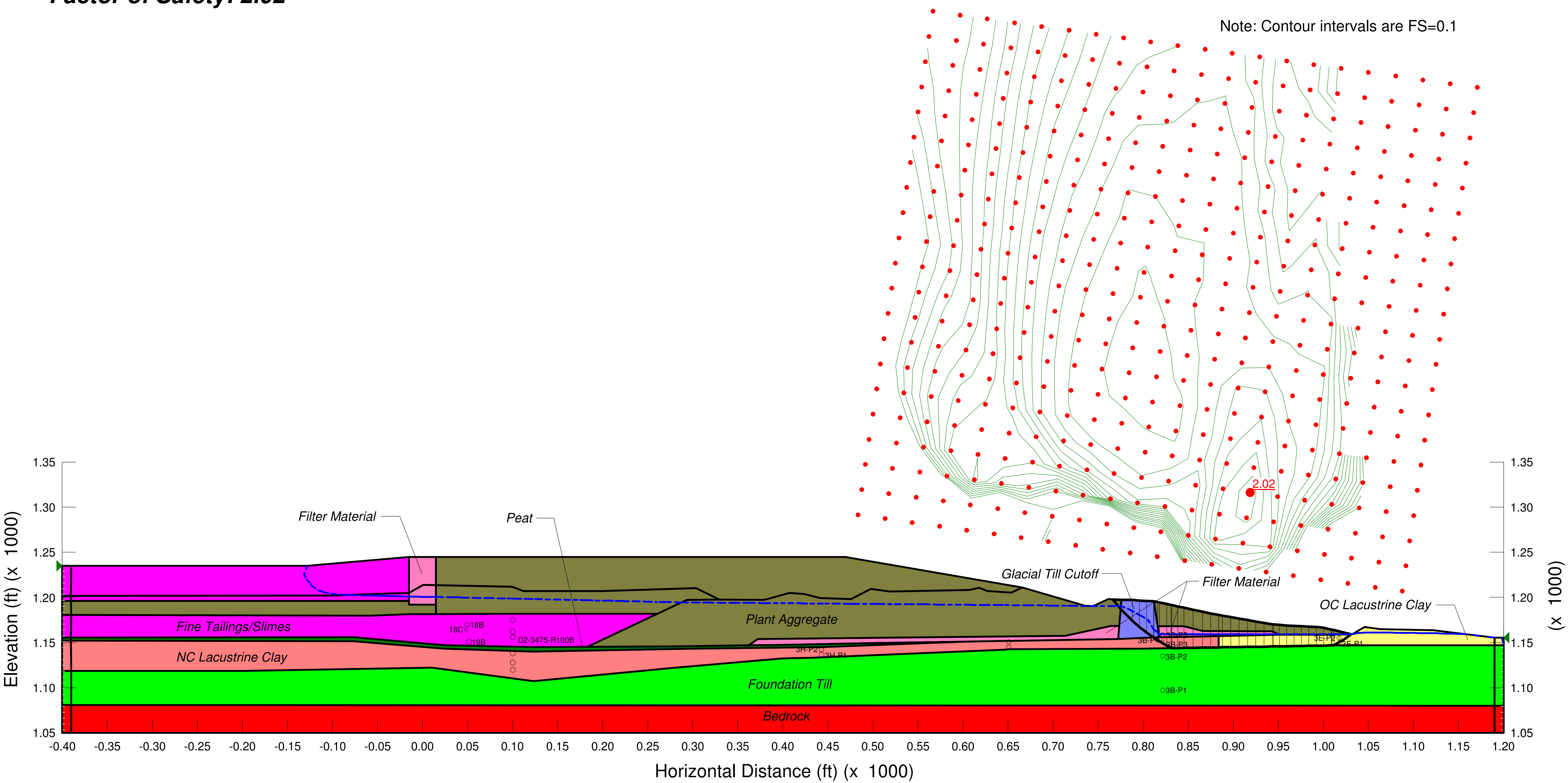
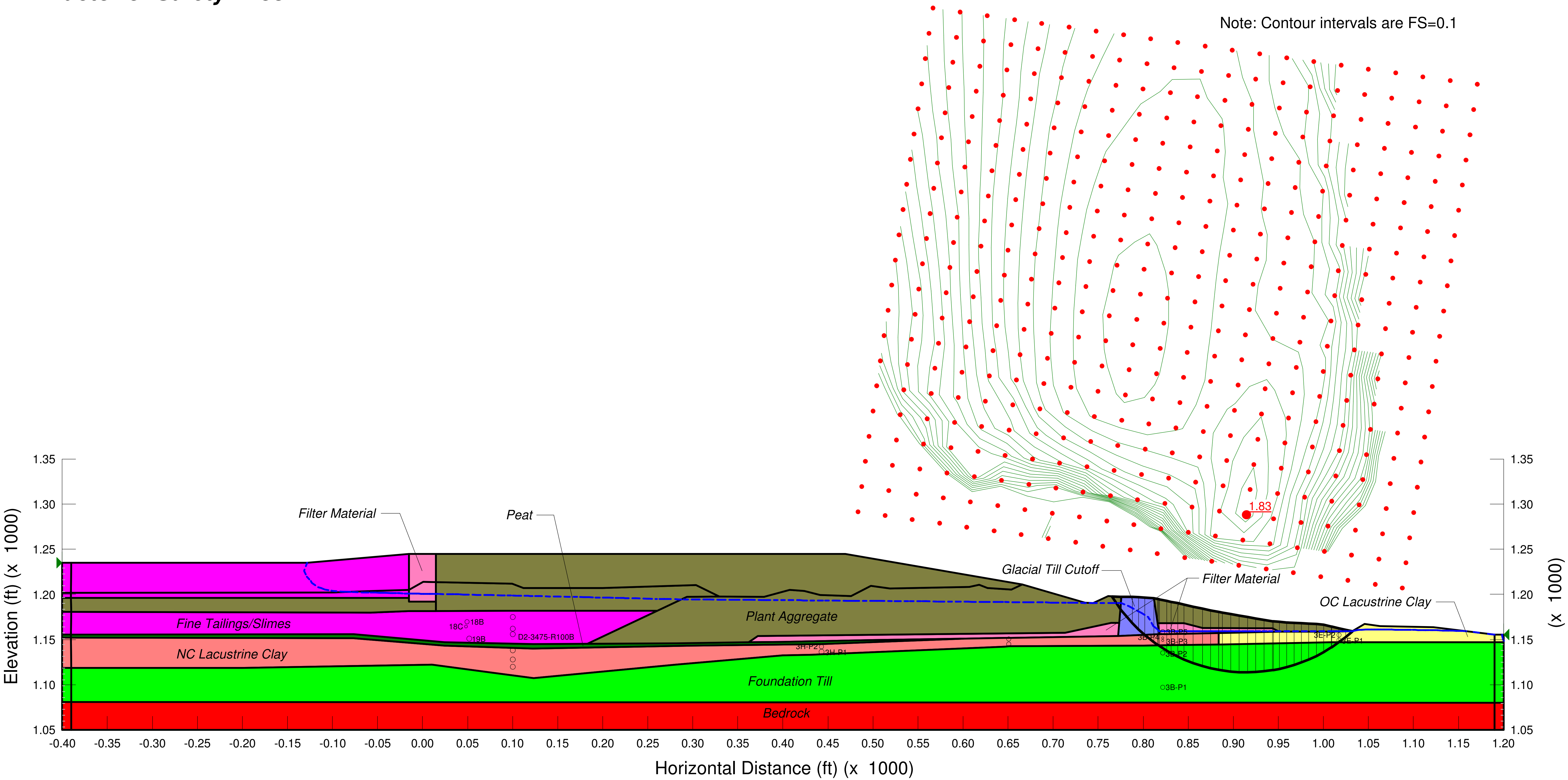
Factor of Safety: 1.78



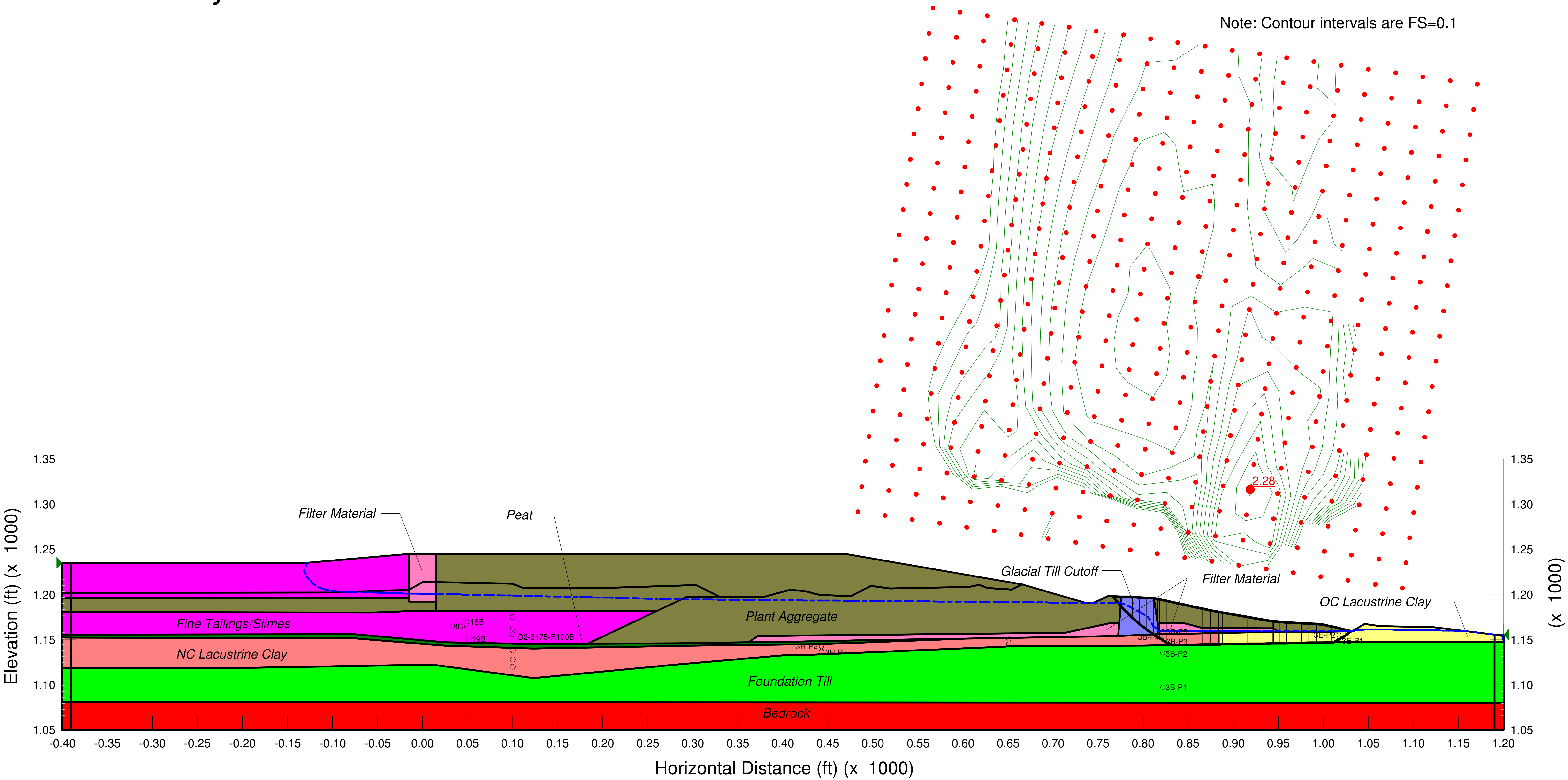
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.2, FM Block
File Name: D2_S3475_E1245_USSA_LC7_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.02



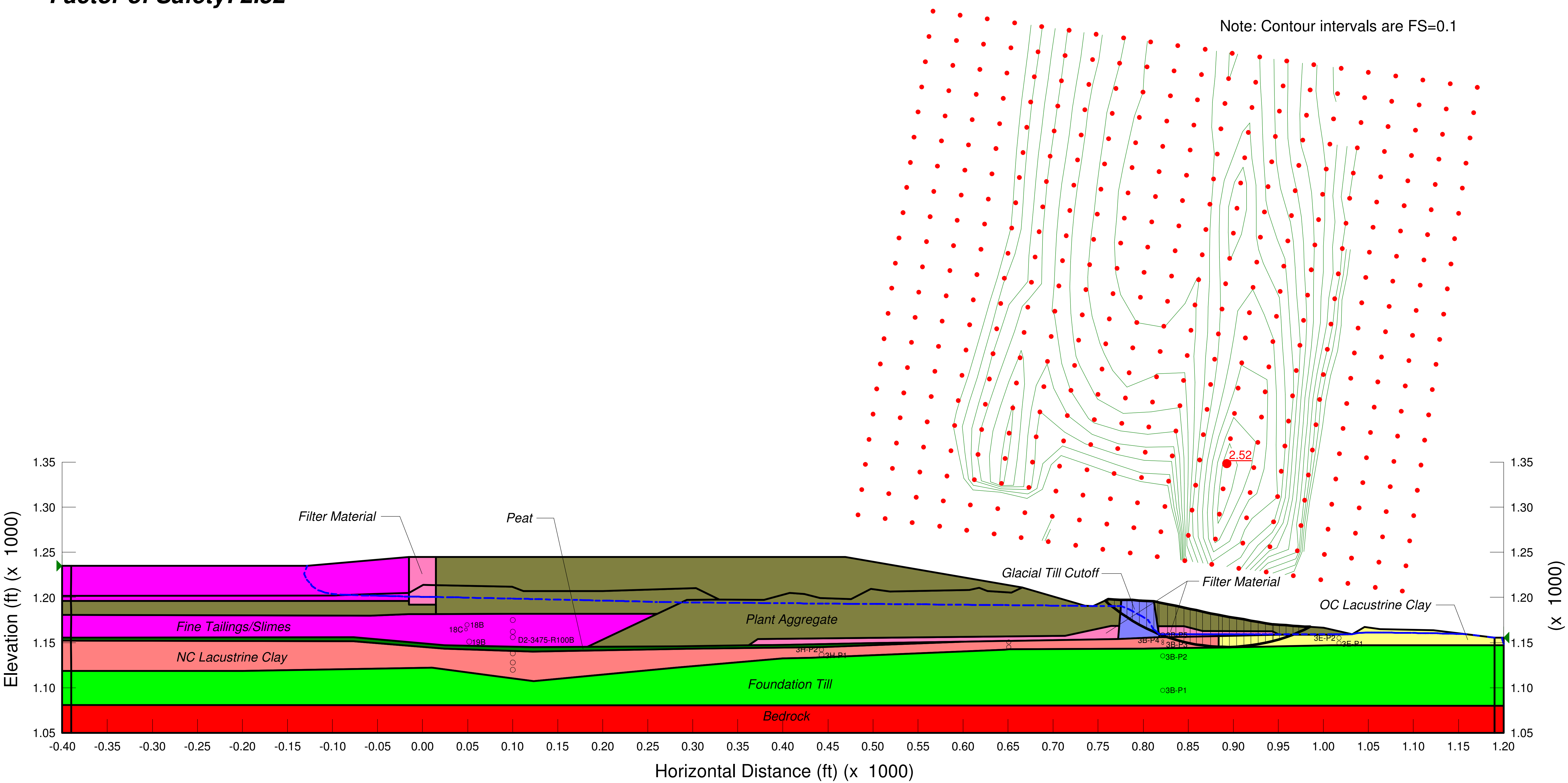
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D2_S3475_E1245_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 1.83



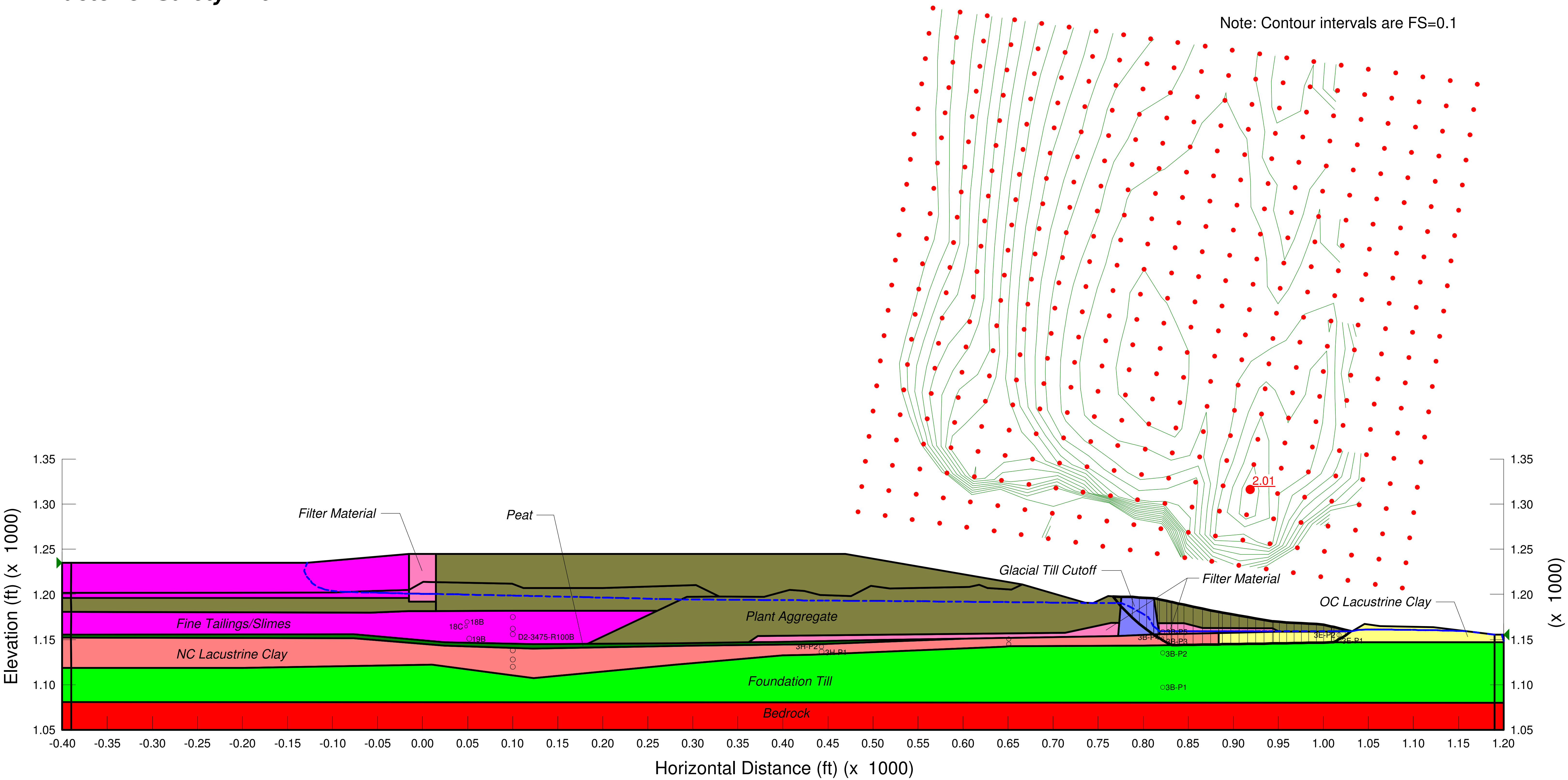
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D2_S3475_E1245_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 6/19/2009
Factor of Safety: 2.28



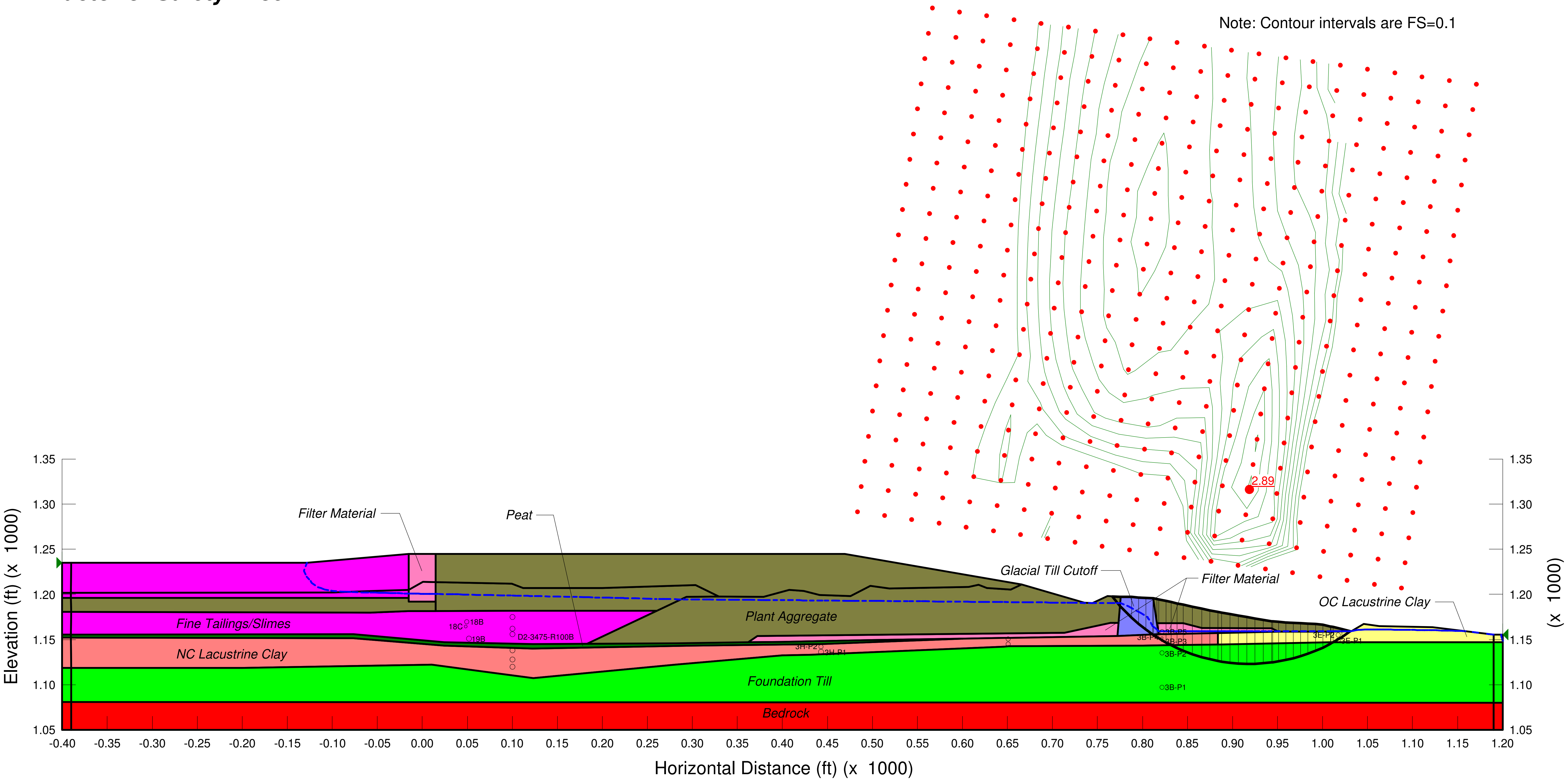
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Toe
File Name: D2_S3475_E1245_ESSA_LC1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.52



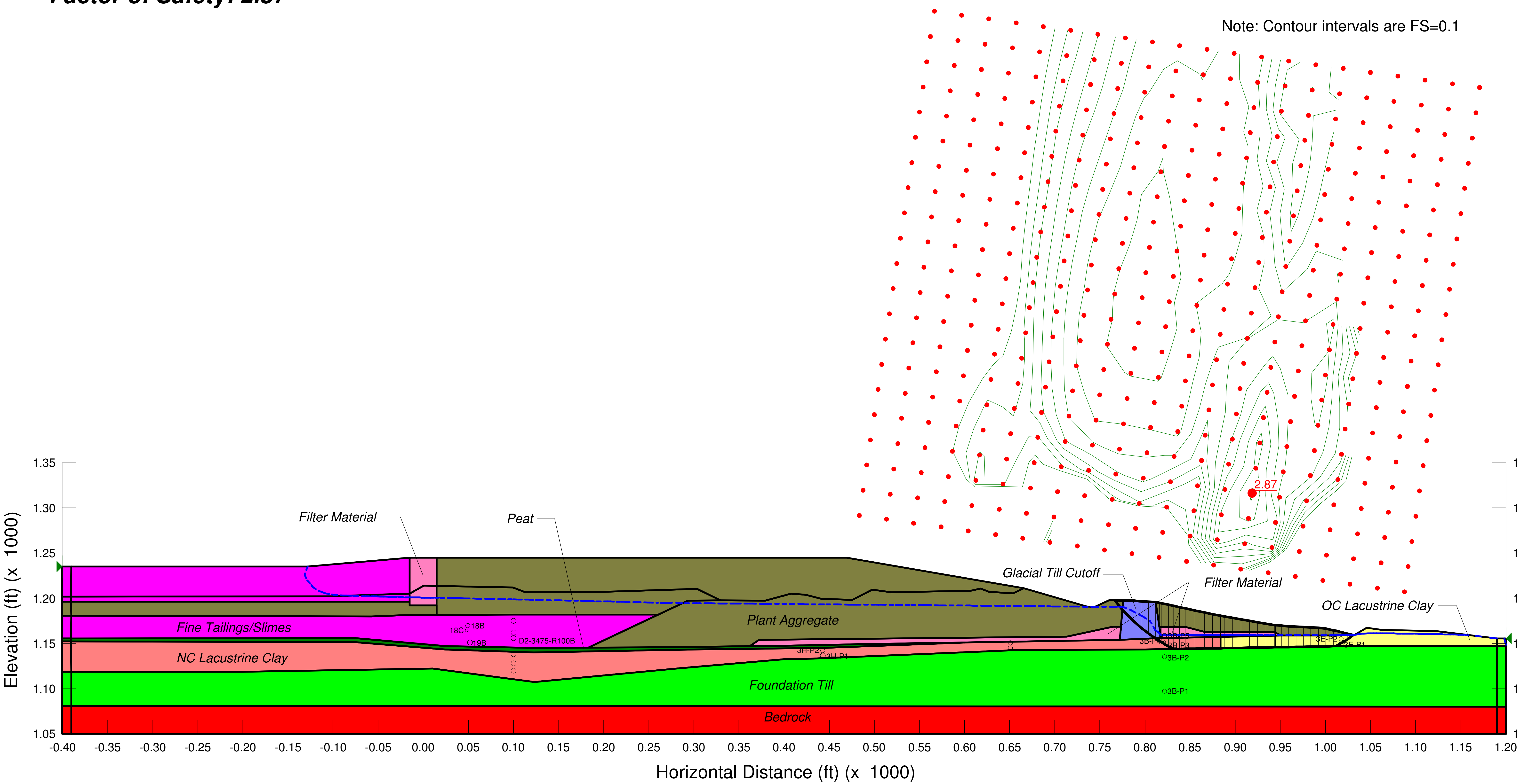
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Block
File Name: D2_S3475_E1245_ESSA_LC1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.01



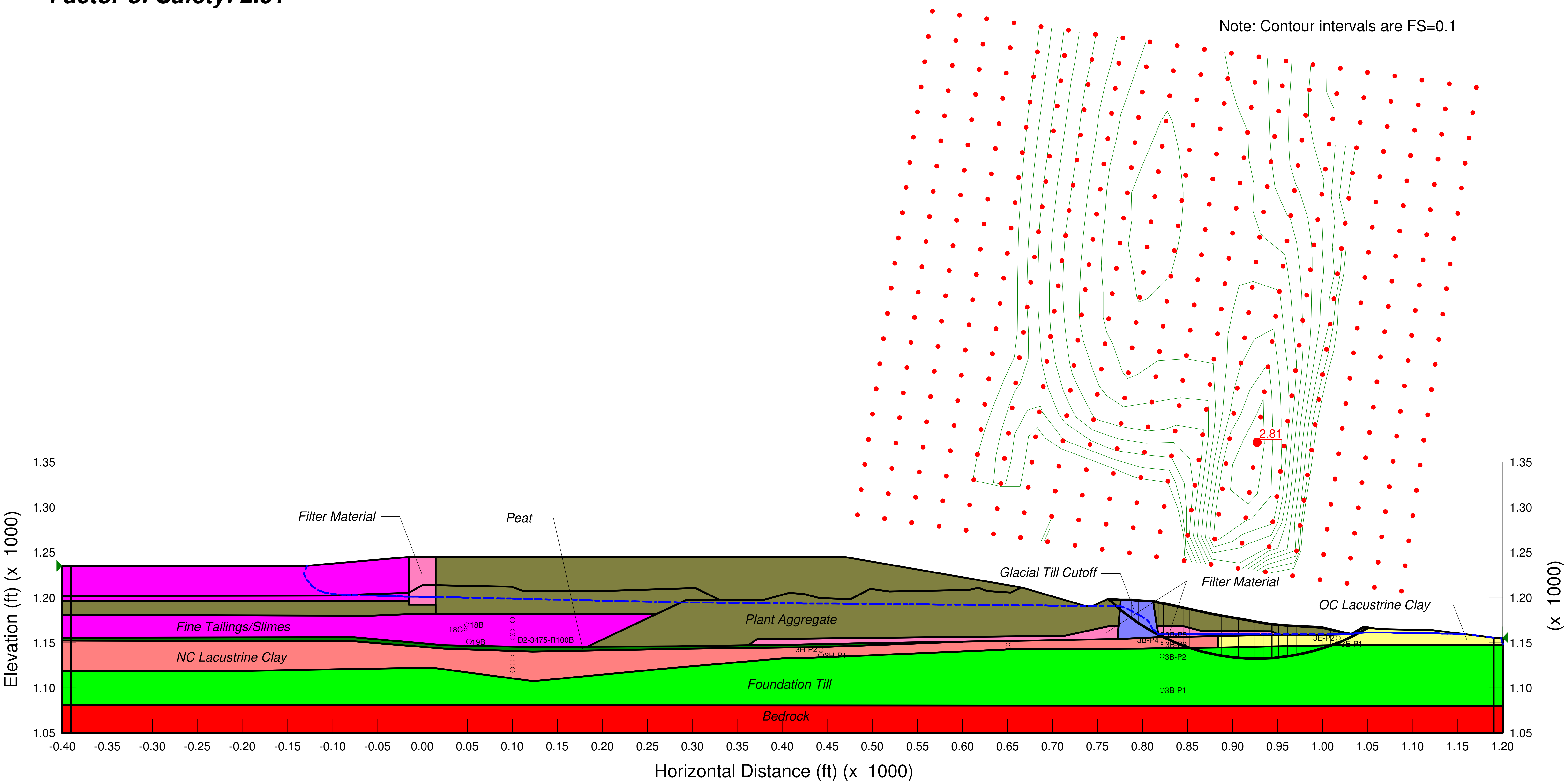
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Toe
File Name: D2_S3475_E1245_ESSA_LC2_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.89



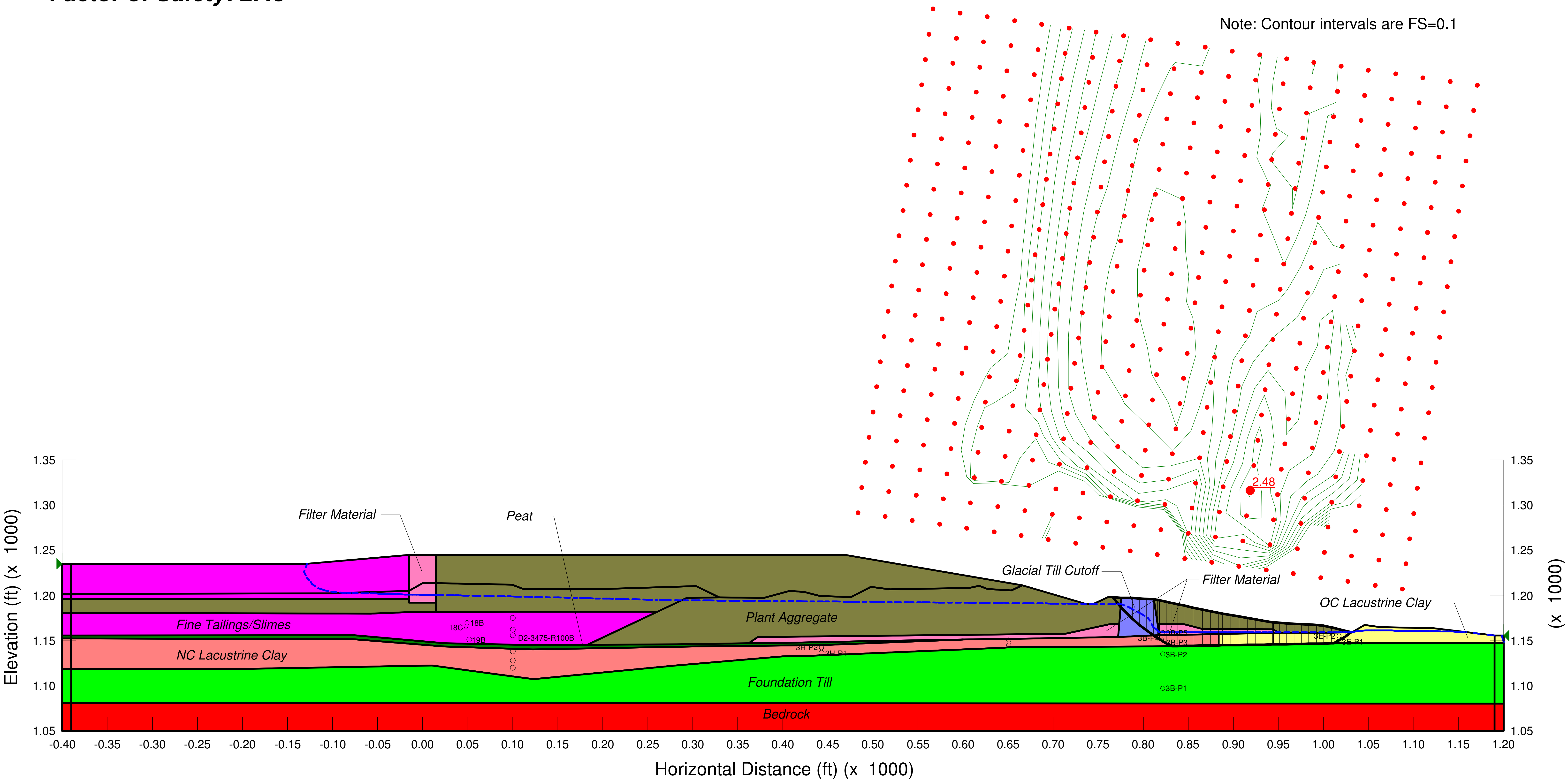
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Block
File Name: D2_S3475_E1245_ESSA_LC2_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.87



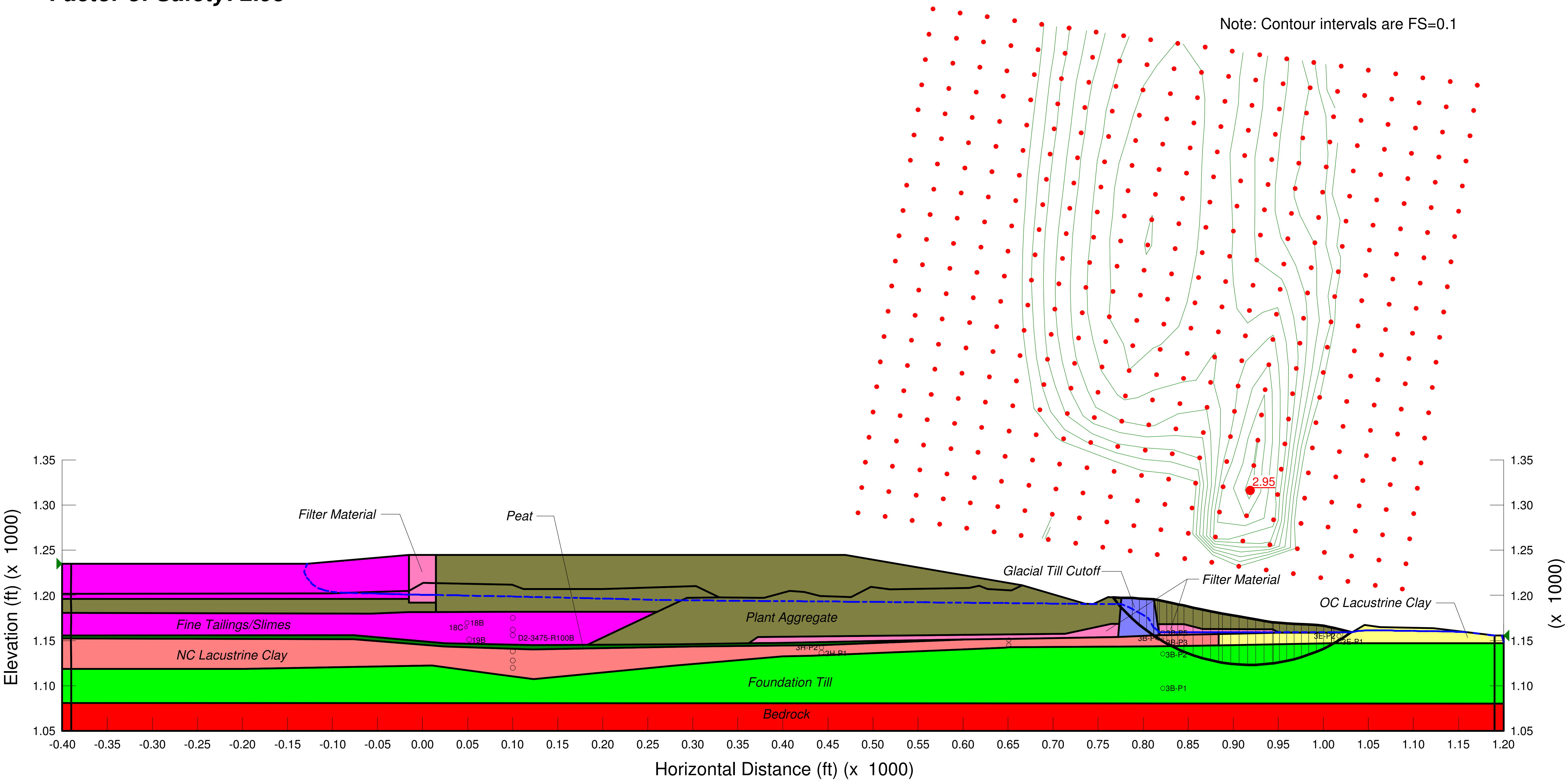
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Toe
File Name: D2_S3475_E1245_ESSA_LC3_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.81



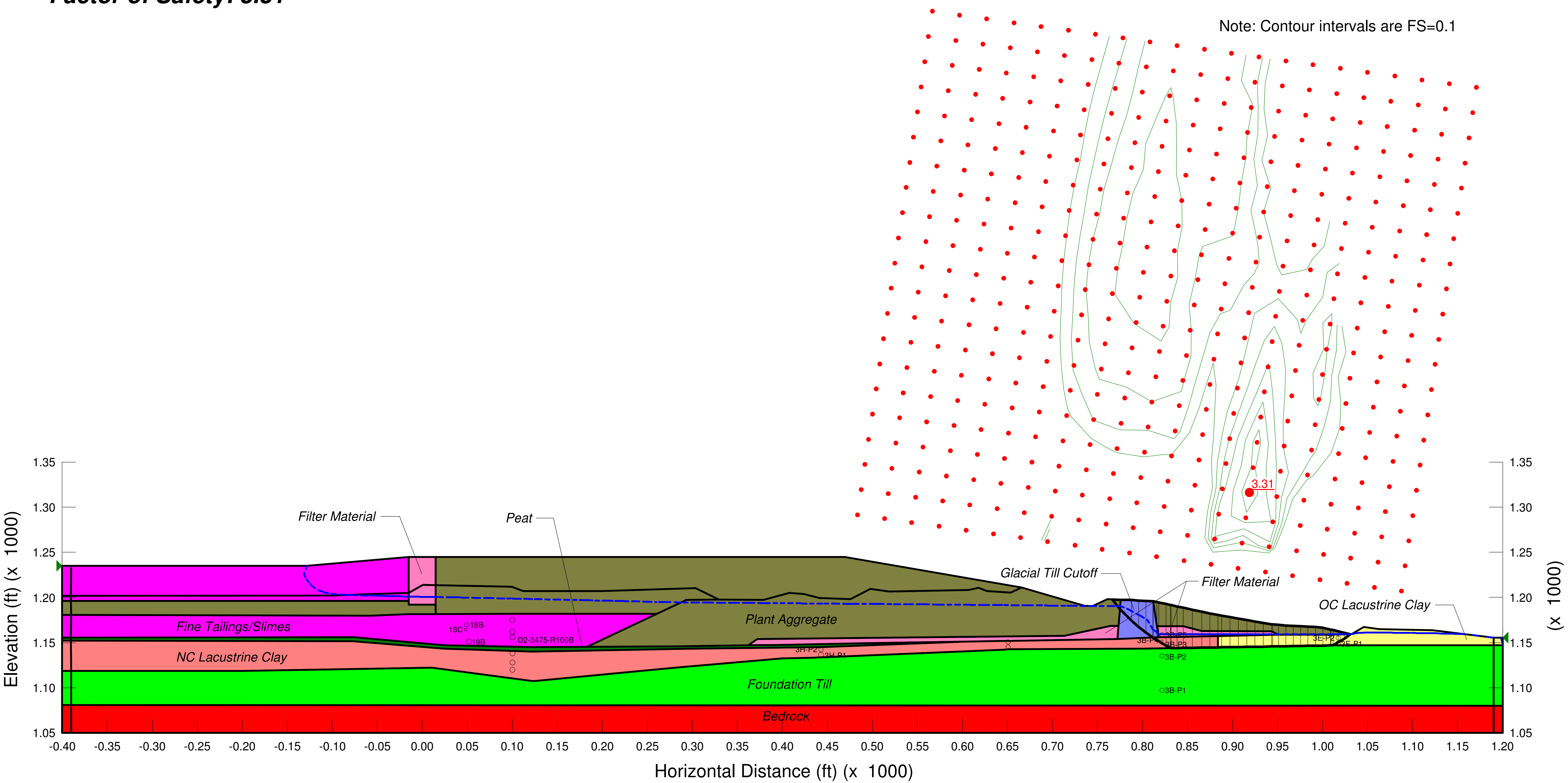
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Block
File Name: D2_S3475_E1245_ESSA_LC3_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.48



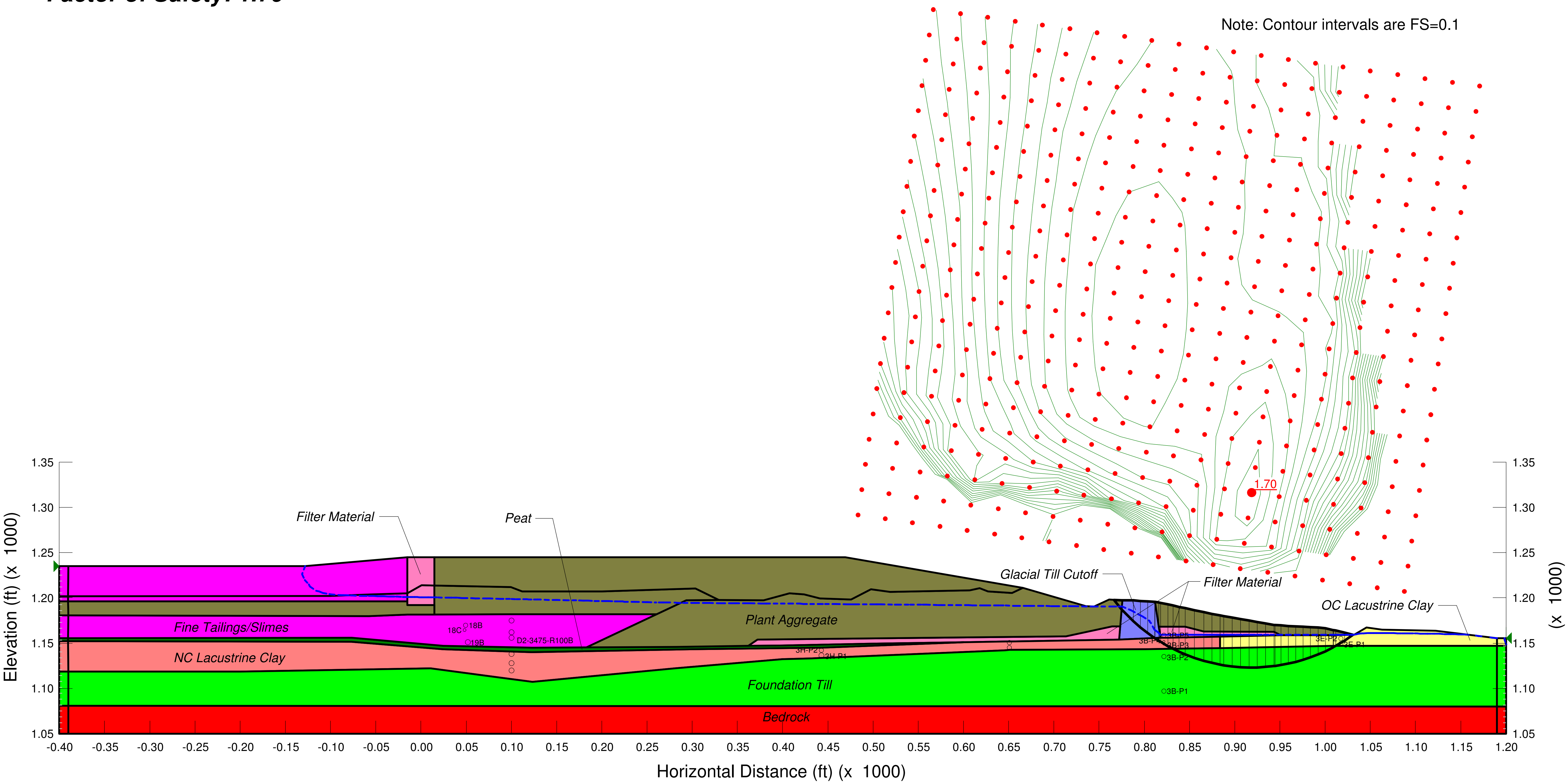
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Toe
File Name: D2_S3475_E1245_ESSA_LC4_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.95



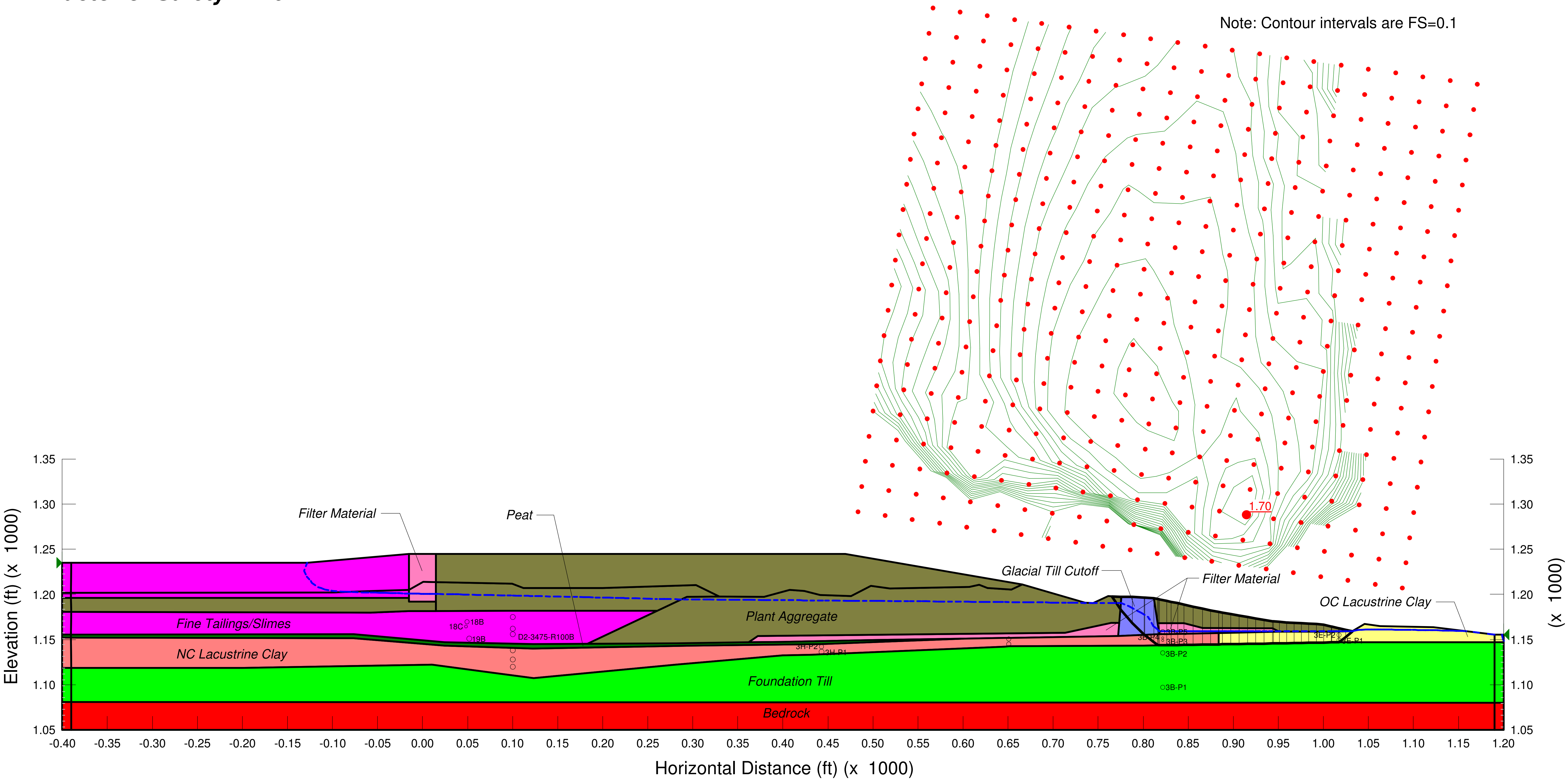
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Block
File Name: D2_S3475_E1245_ESSA_LC4_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 3.31



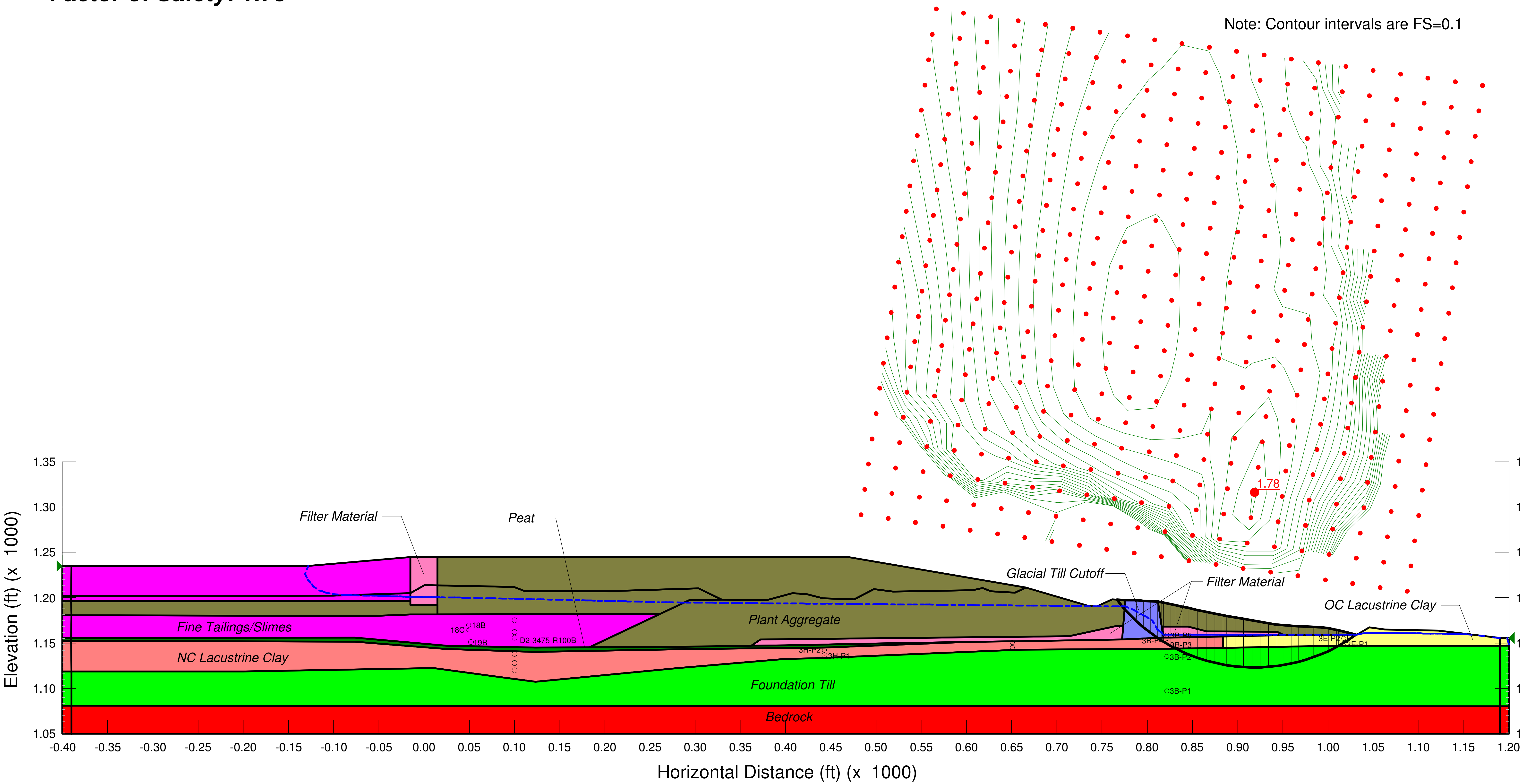
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.1, FM Toe
File Name: D2_S3475_E1245_USSA_LC5_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.70



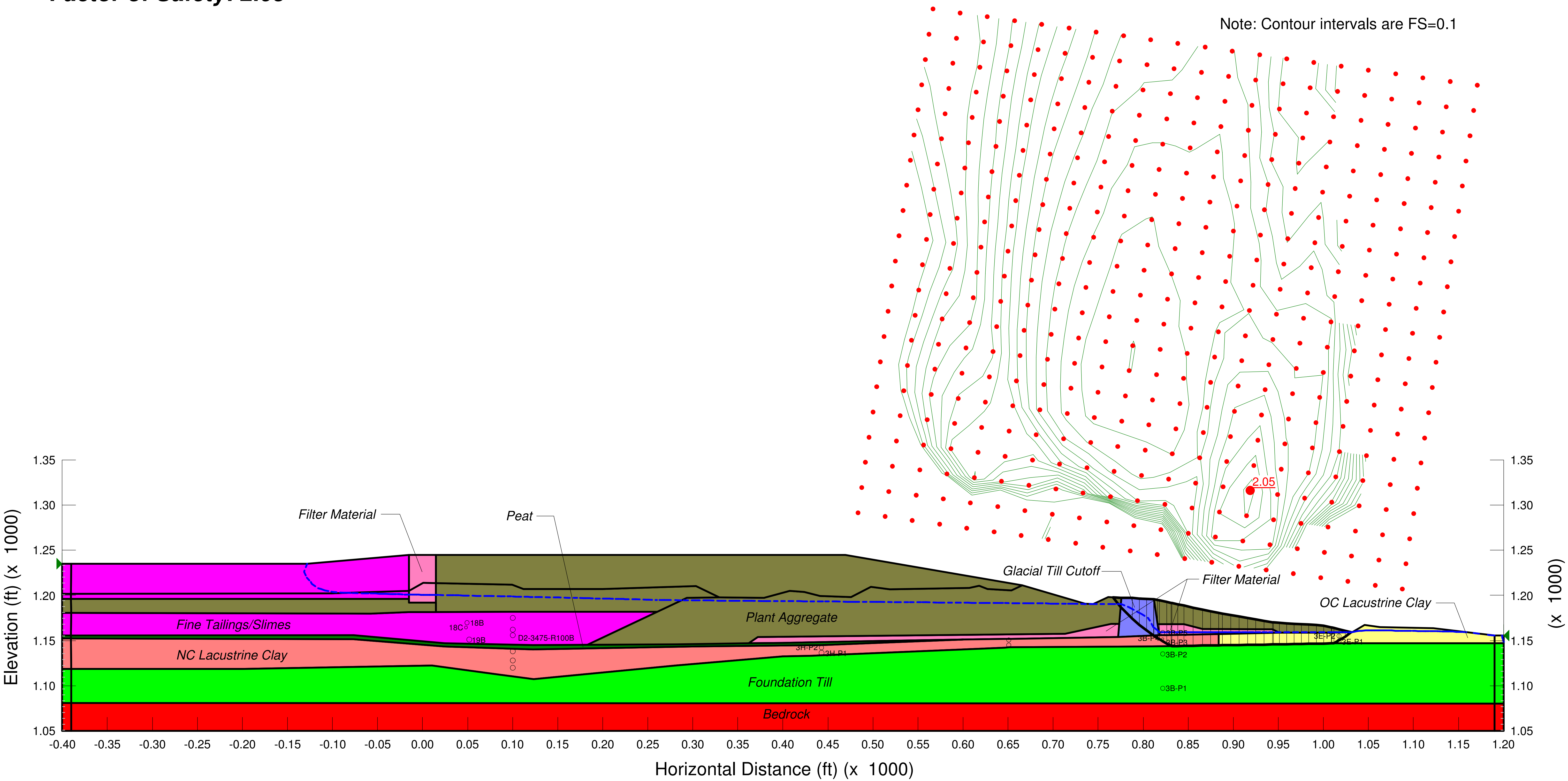
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D2_S3475_E1245_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.70



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D2_S3475_E1245_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.78



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D2_S3475_E1245_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.05



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.1, FM Toe
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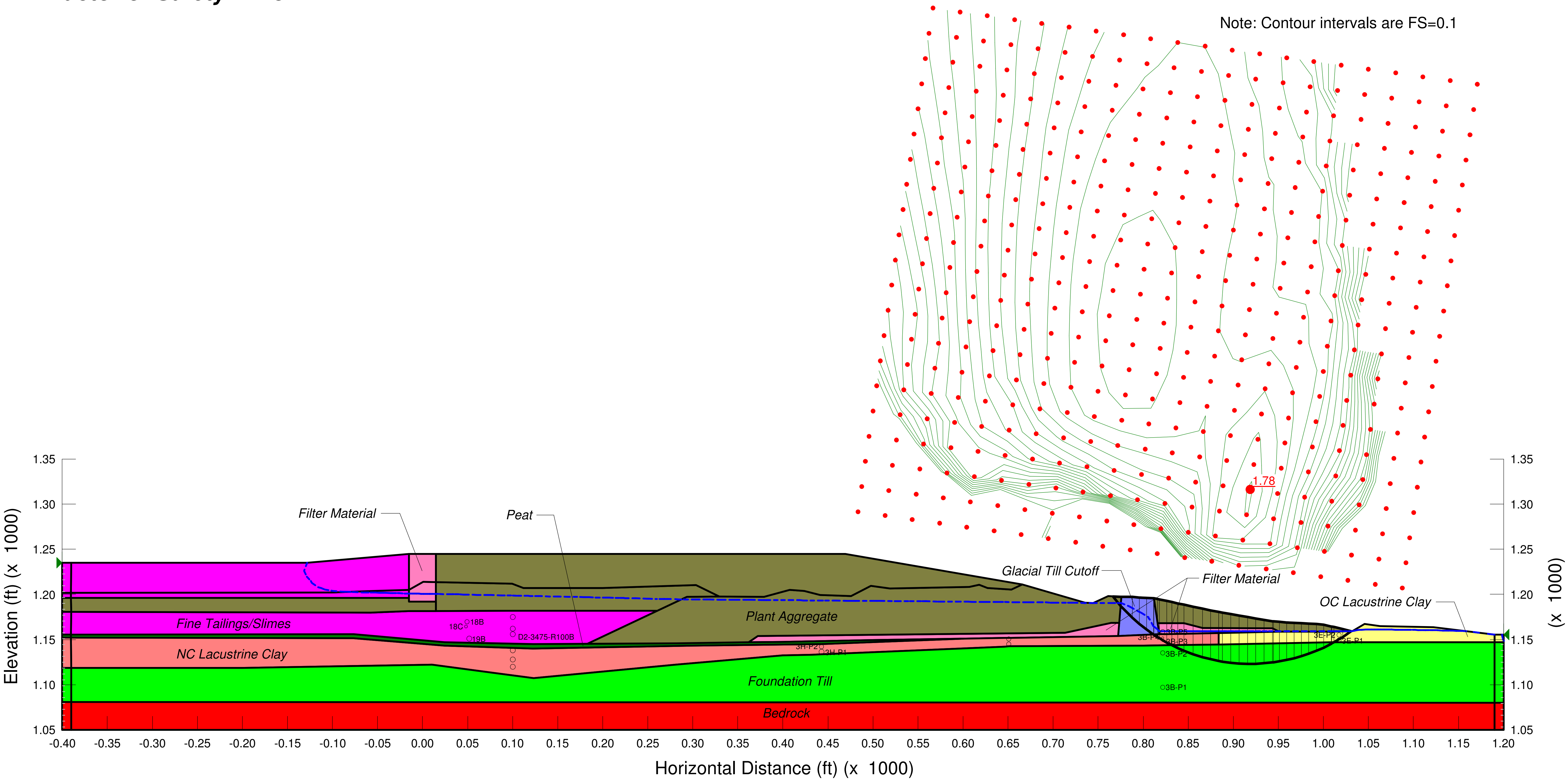
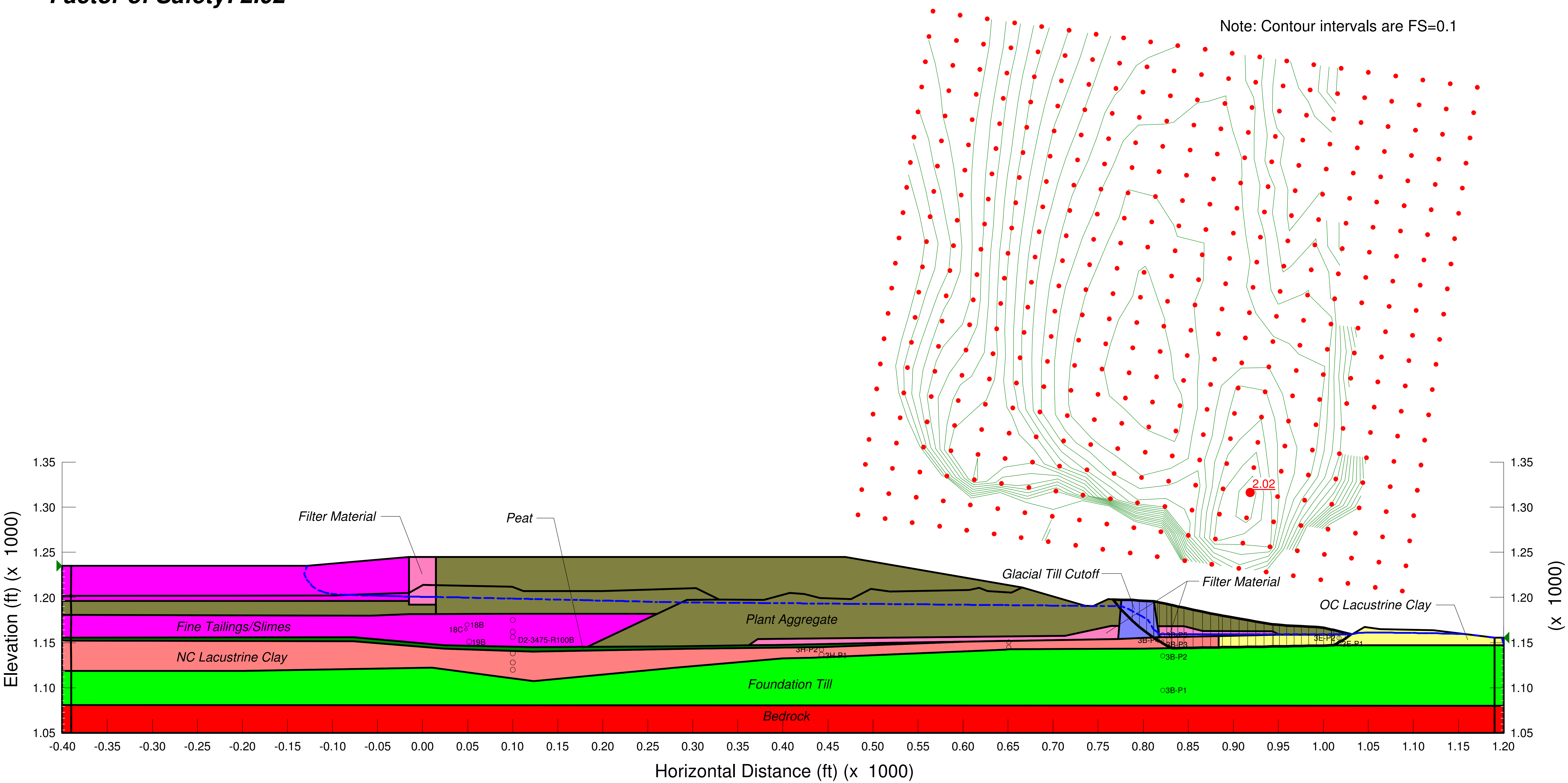
Last Saved Date: 11/17/2008
Factor of Safety: 1.78



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FT 0.1, FM Block
File Name: D2_S3475_E1245_USSA_LC7_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.02



Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D2_S3475_E1245_USSA_LC8_FT1_FM1.gsz
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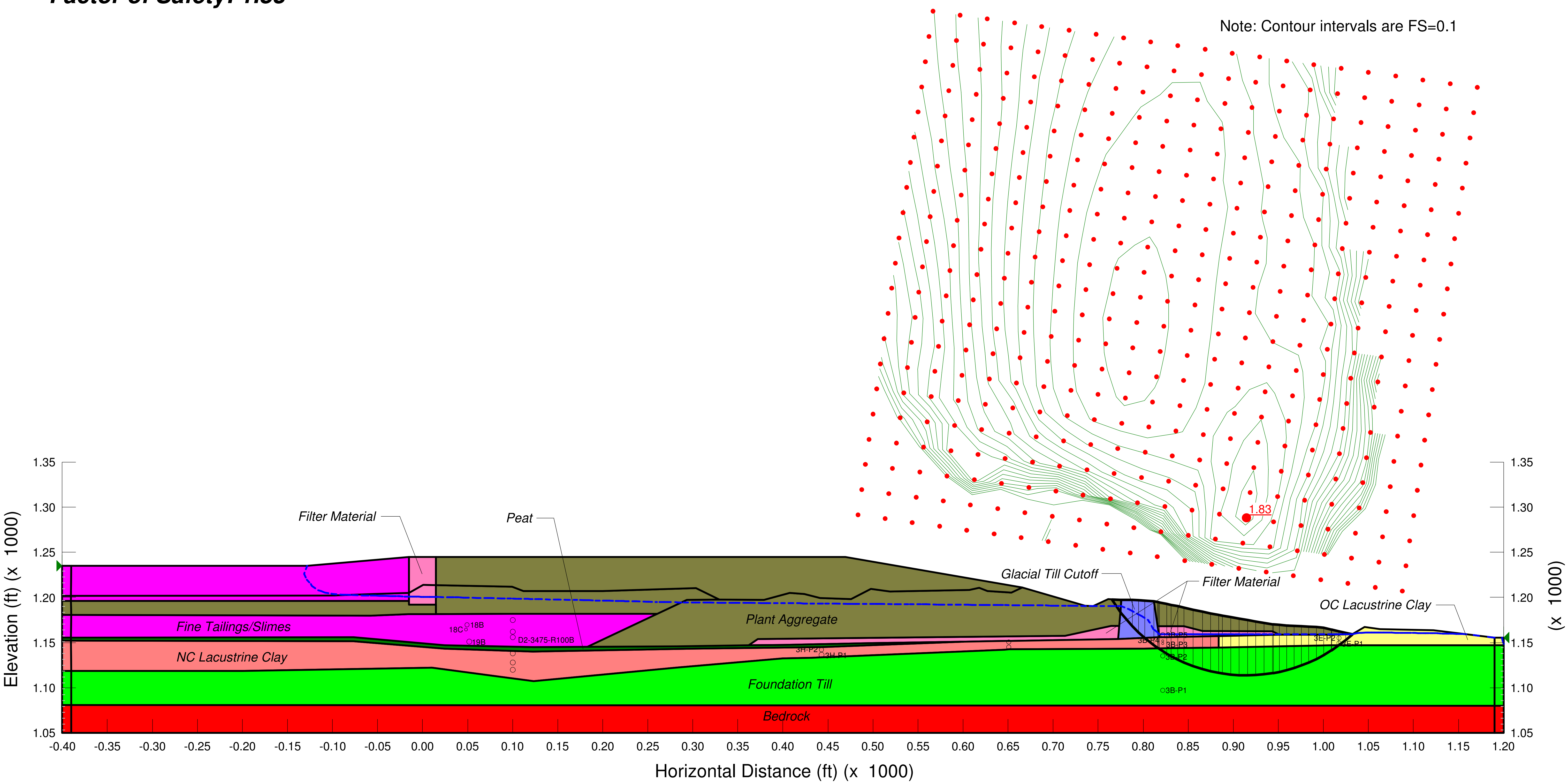
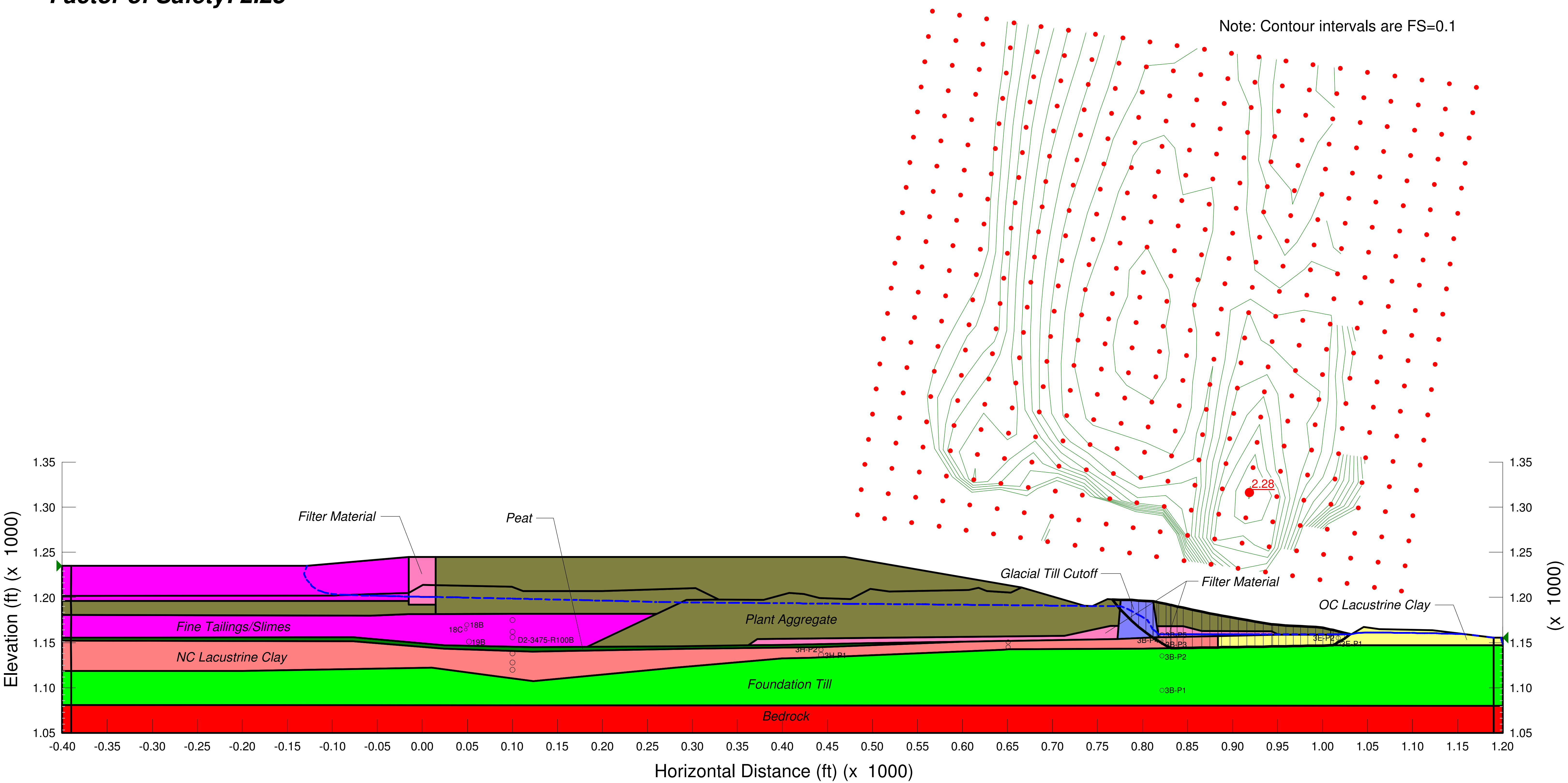
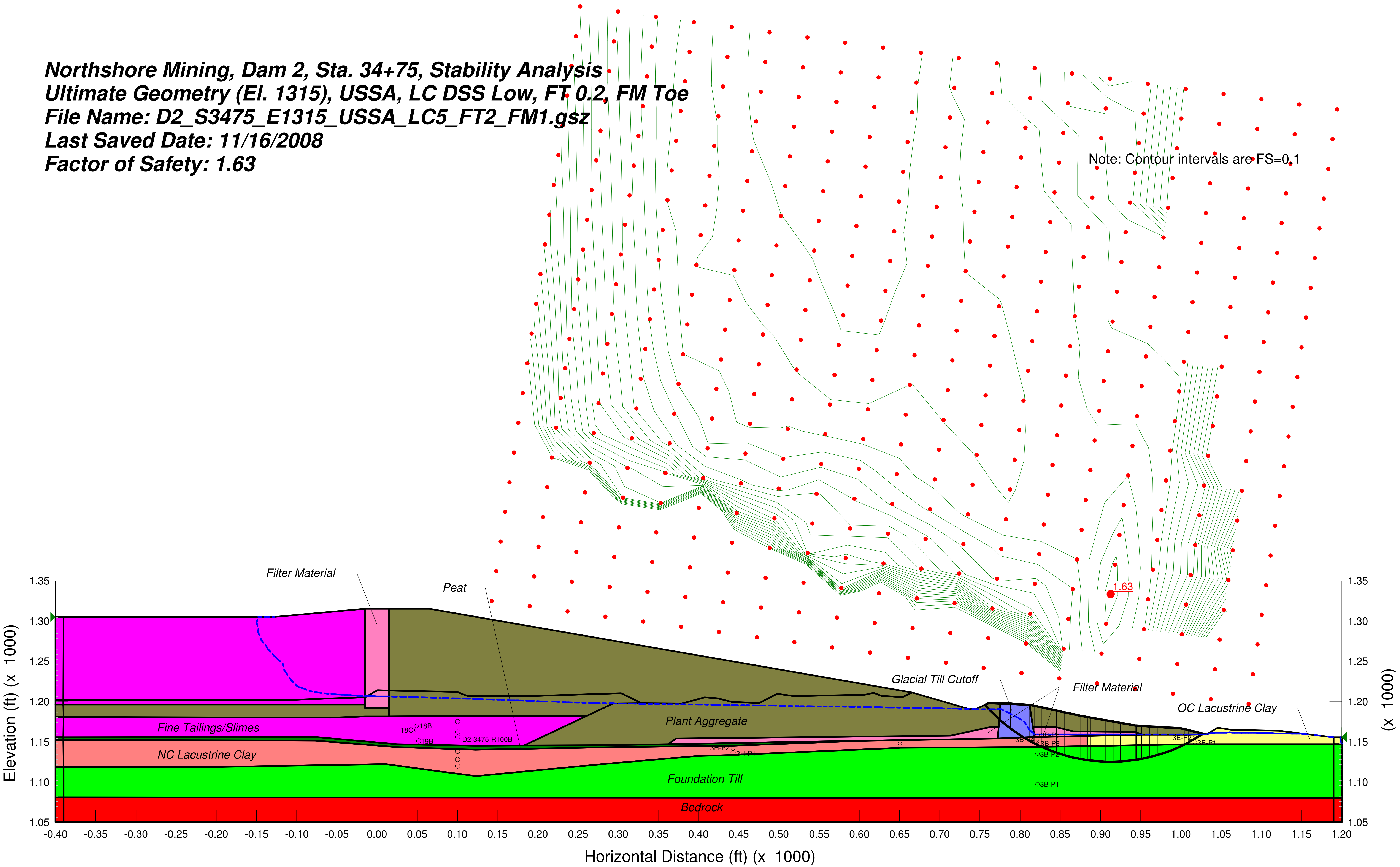
Factor of Safety: 1.83



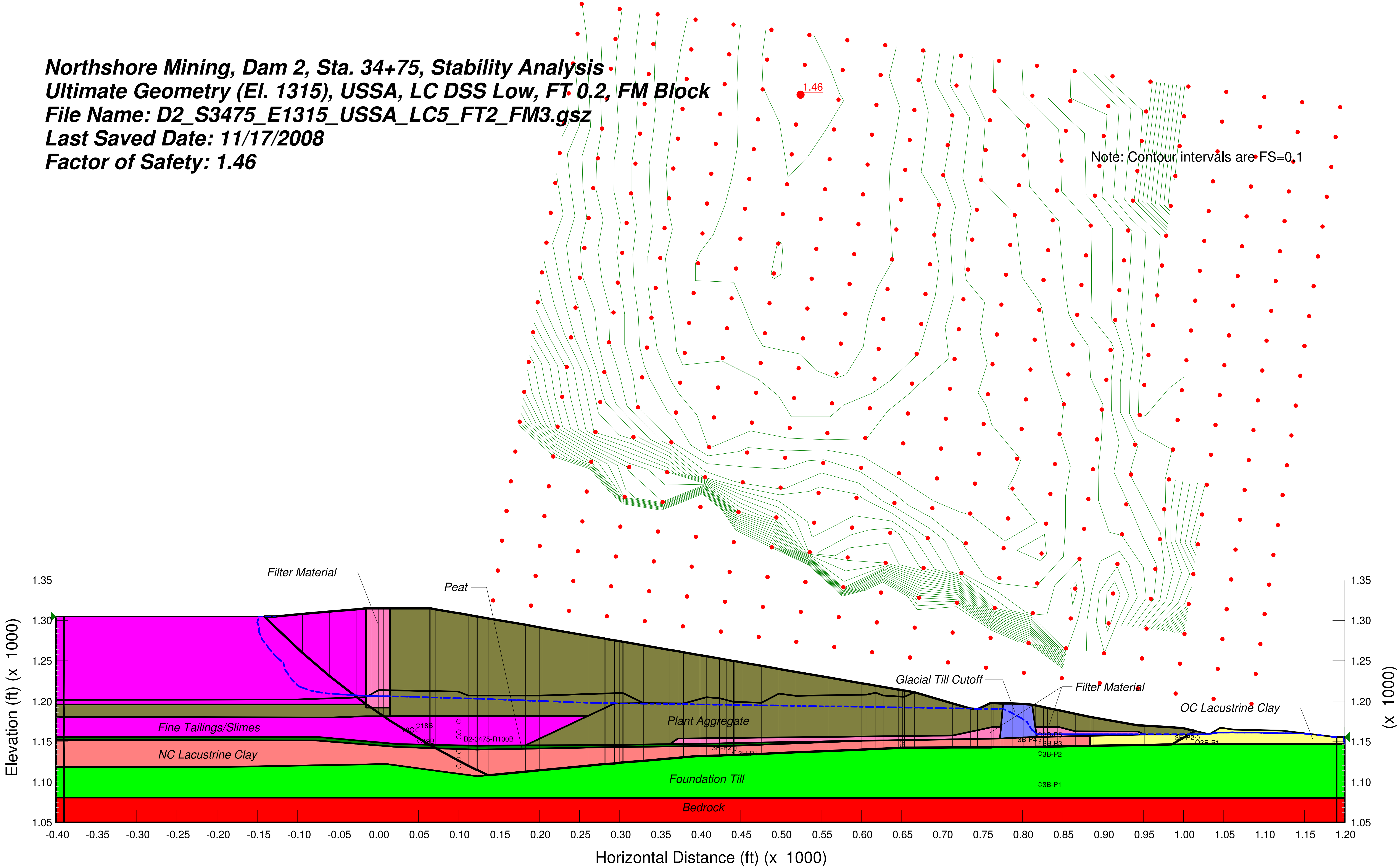
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D2_S3475_E1245_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 2.28



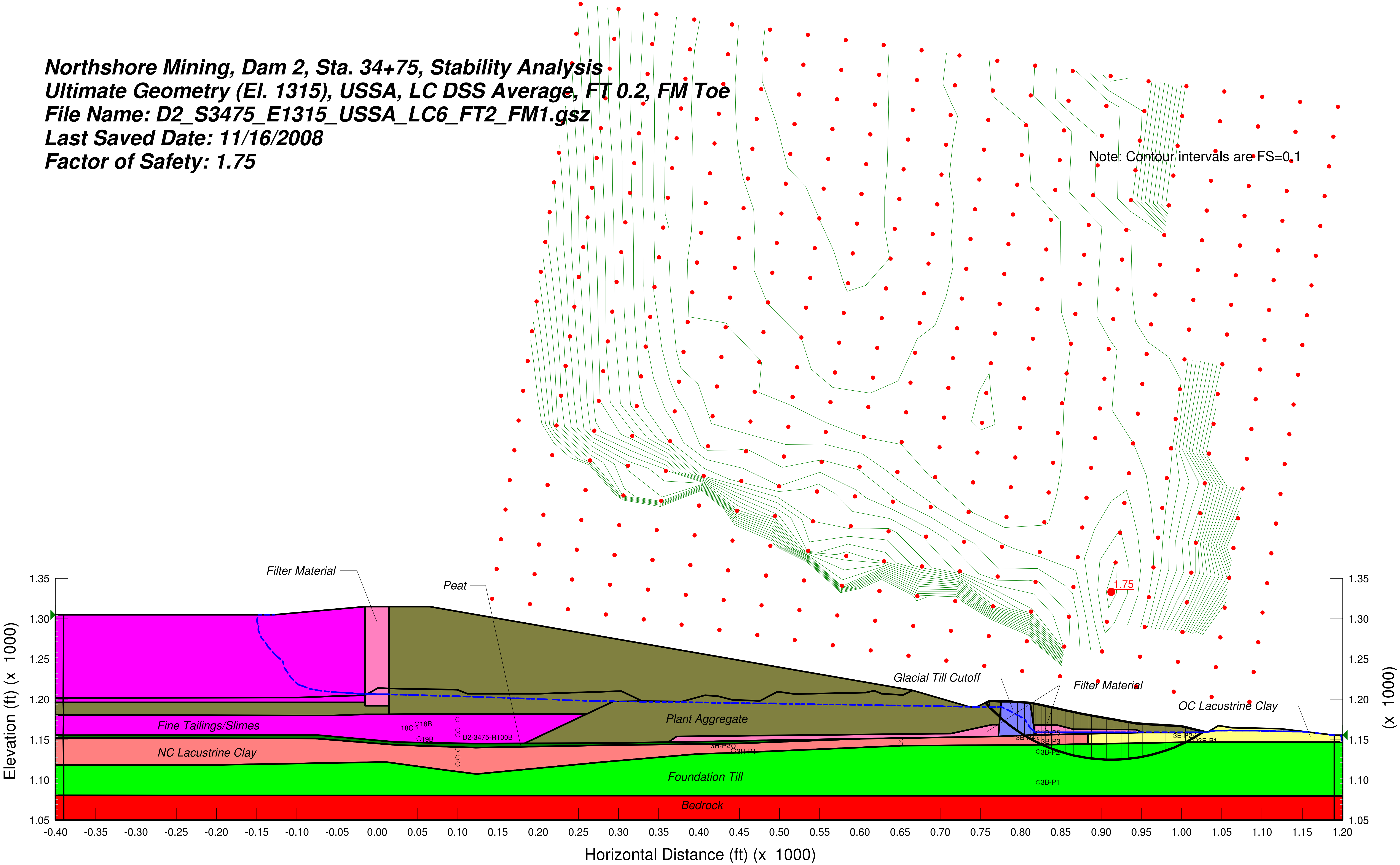
Proposed Geometry El. 1,315 feet


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.2, FM Toe
File Name: D2_S3475_E1315_USSA_LC5_FT2_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.63
Note: Contour intervals are FS=0.1
1.63
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Plant Aggregate
Fine Tailings/Slimes
NC Lacustrine Clay
Foundation Till
Bedrock
Elevation (ft) (x 1000)
Horizontal Distance (ft) (x 1000)
(x 1000)

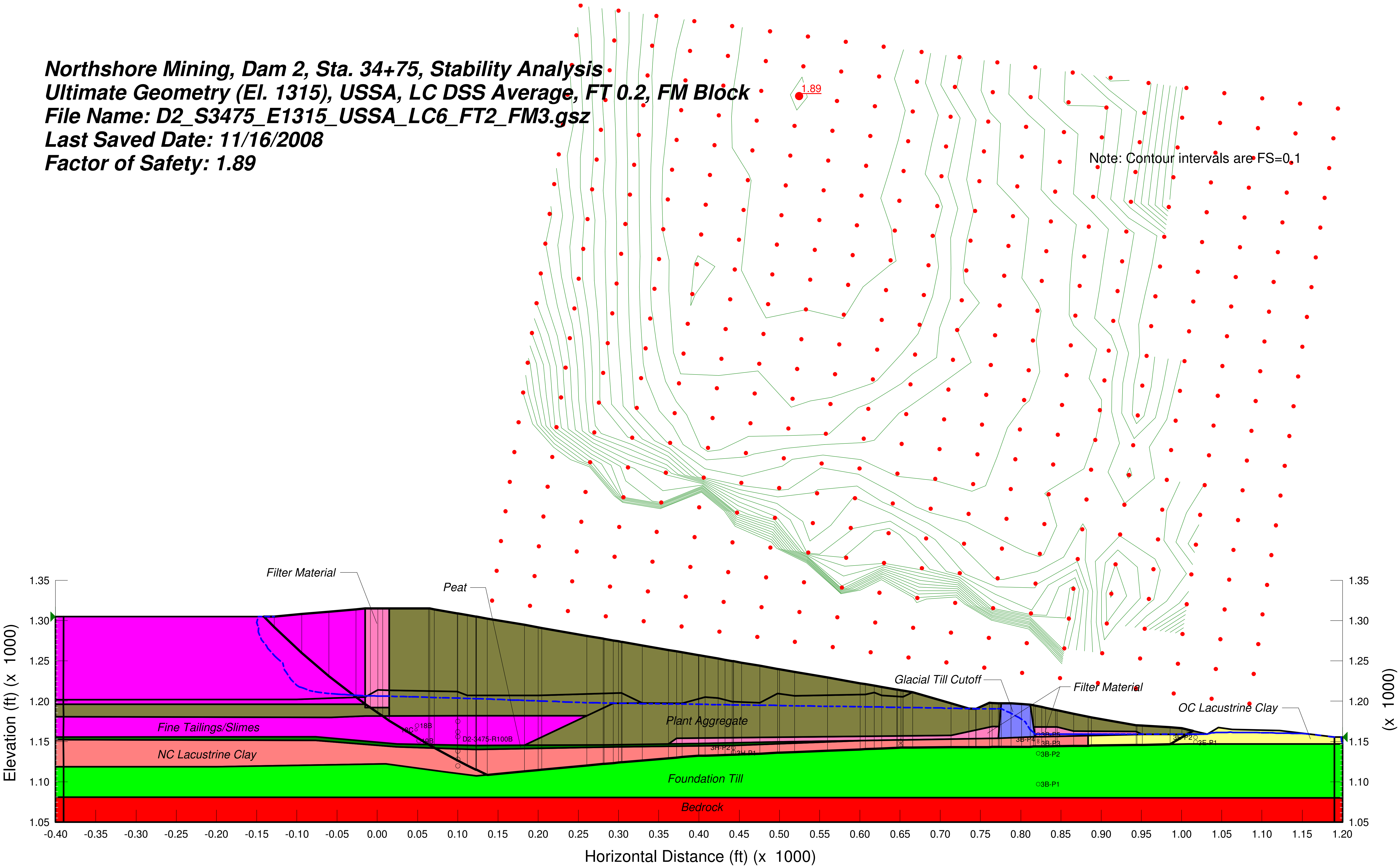
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.2, FM Block
File Name: D2_S3475_E1315_USSA_LC5_FT2_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.46

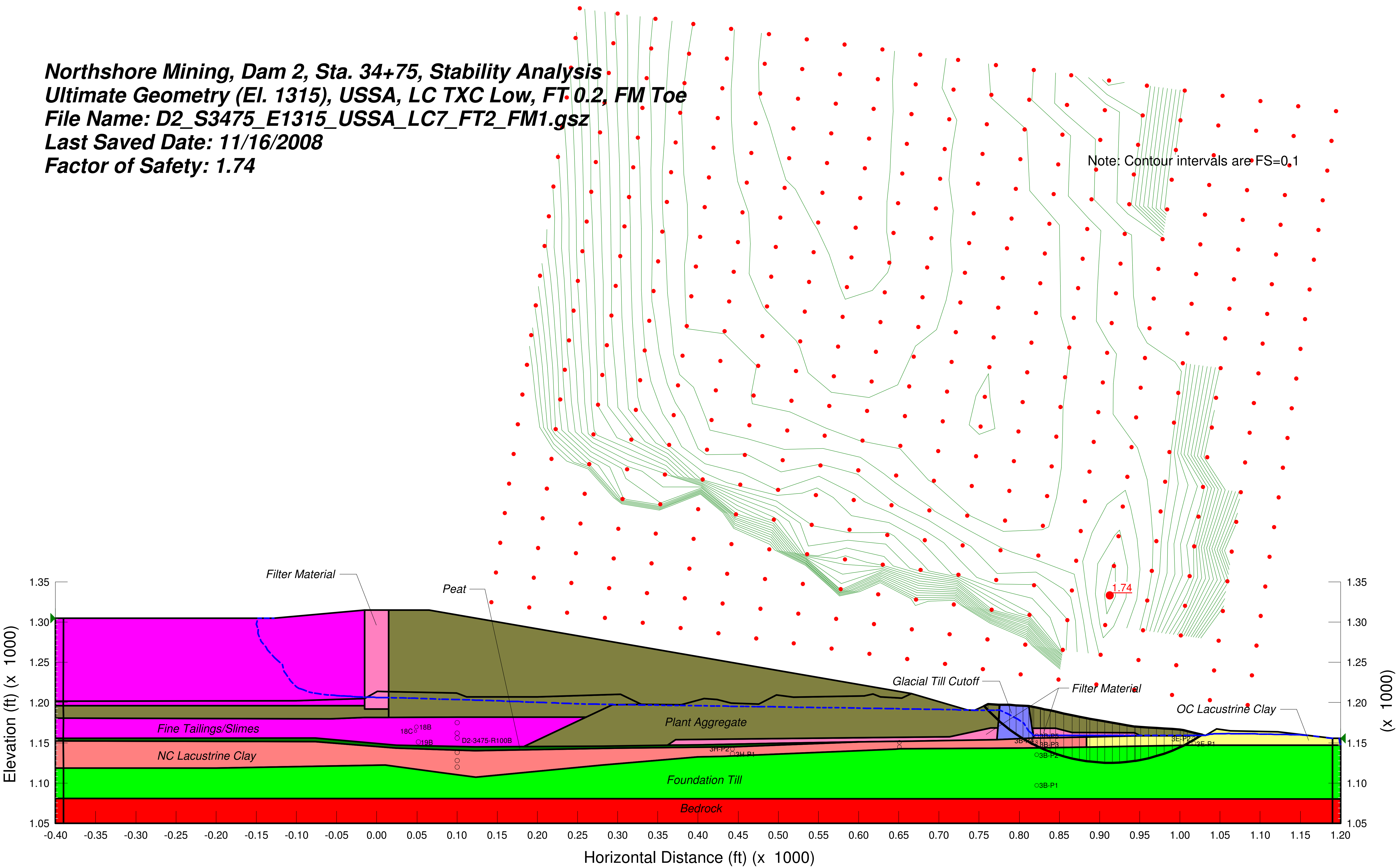


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.2, FM Toe
File Name: D2_S3475_E1315_USSA_LC6_FT2_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.75



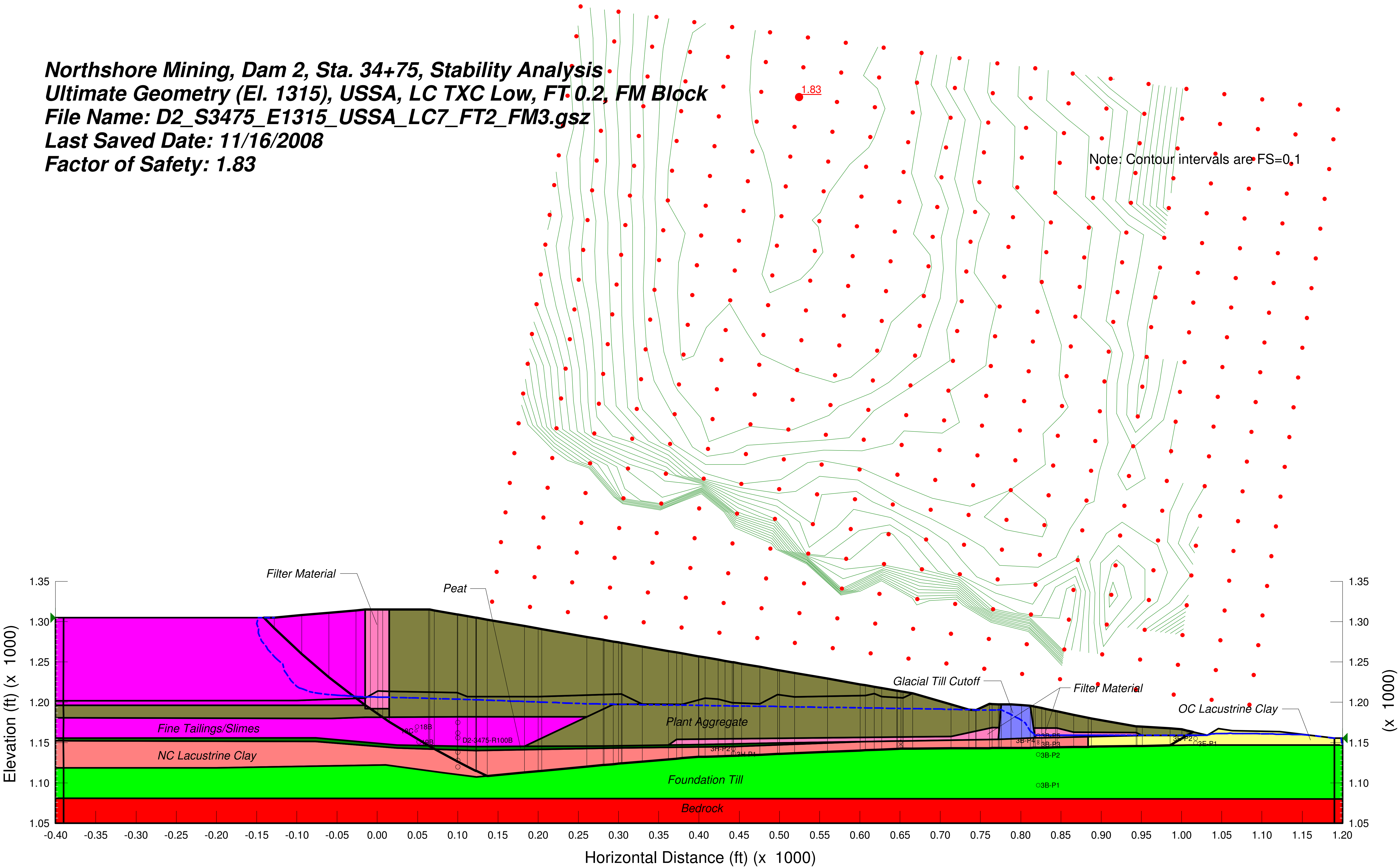
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.2, FM Block
File Name: D2_S3475_E1315_USSA_LC6_FT2_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.89



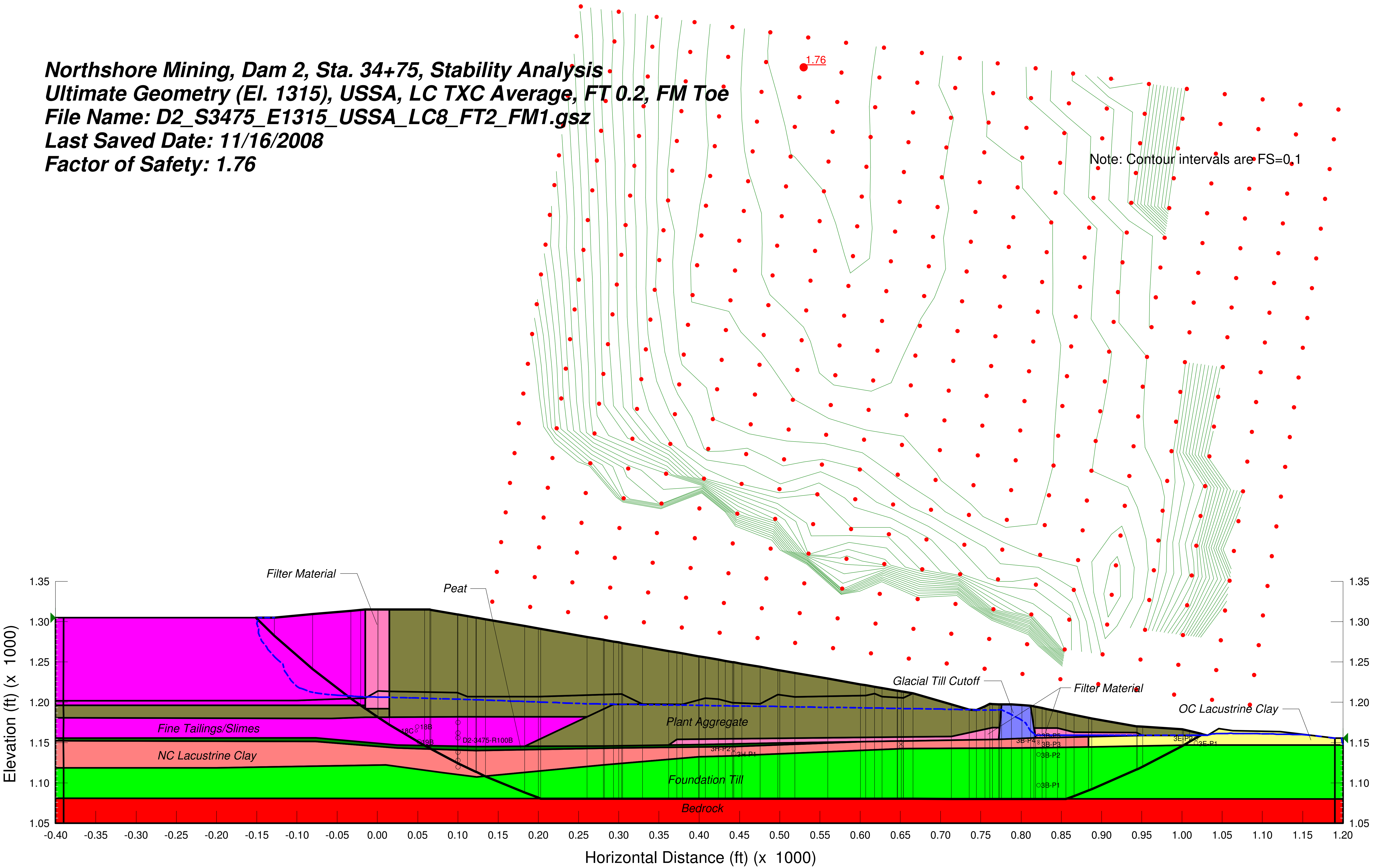


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.2, FM Toe
File Name: D2_S3475_E1315_USSA_LC7_FT2_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.74
Note: Contour intervals are FS=0.1
1.74
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Fine Tailings/Slimes
Plant Aggregate
NC Lacustrine Clay
Foundation Till
Bedrock
Elevation (ft) (x 1000)
Horizontal Distance (ft) (x 1000)
(x 1000)

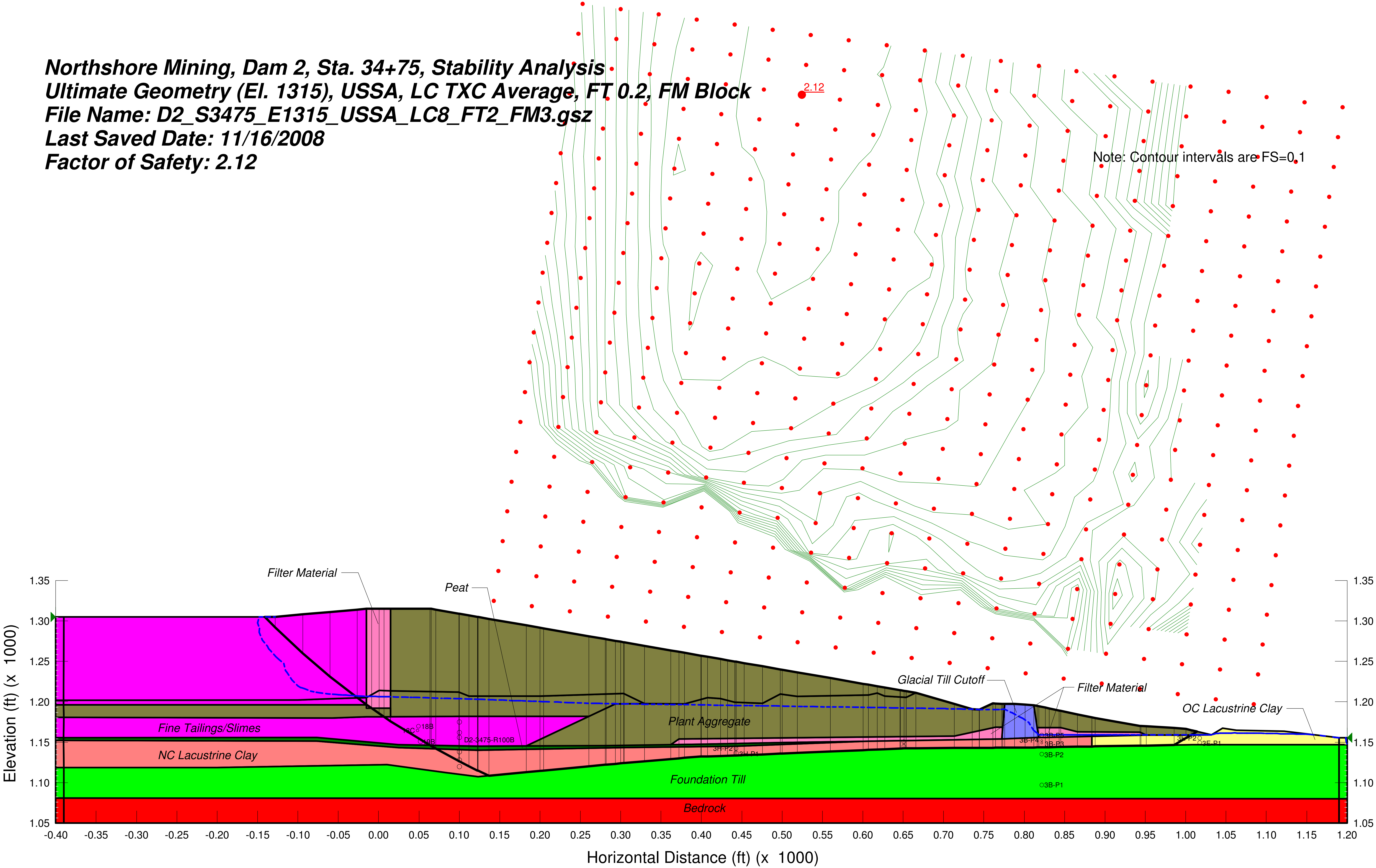
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.2, FM Block
_File Name: D2_S3475_E1315_USSA_LC7_FT2_FM3.gsz_
Last Saved Date: 11/16/2008
Factor of Safety: 1.83



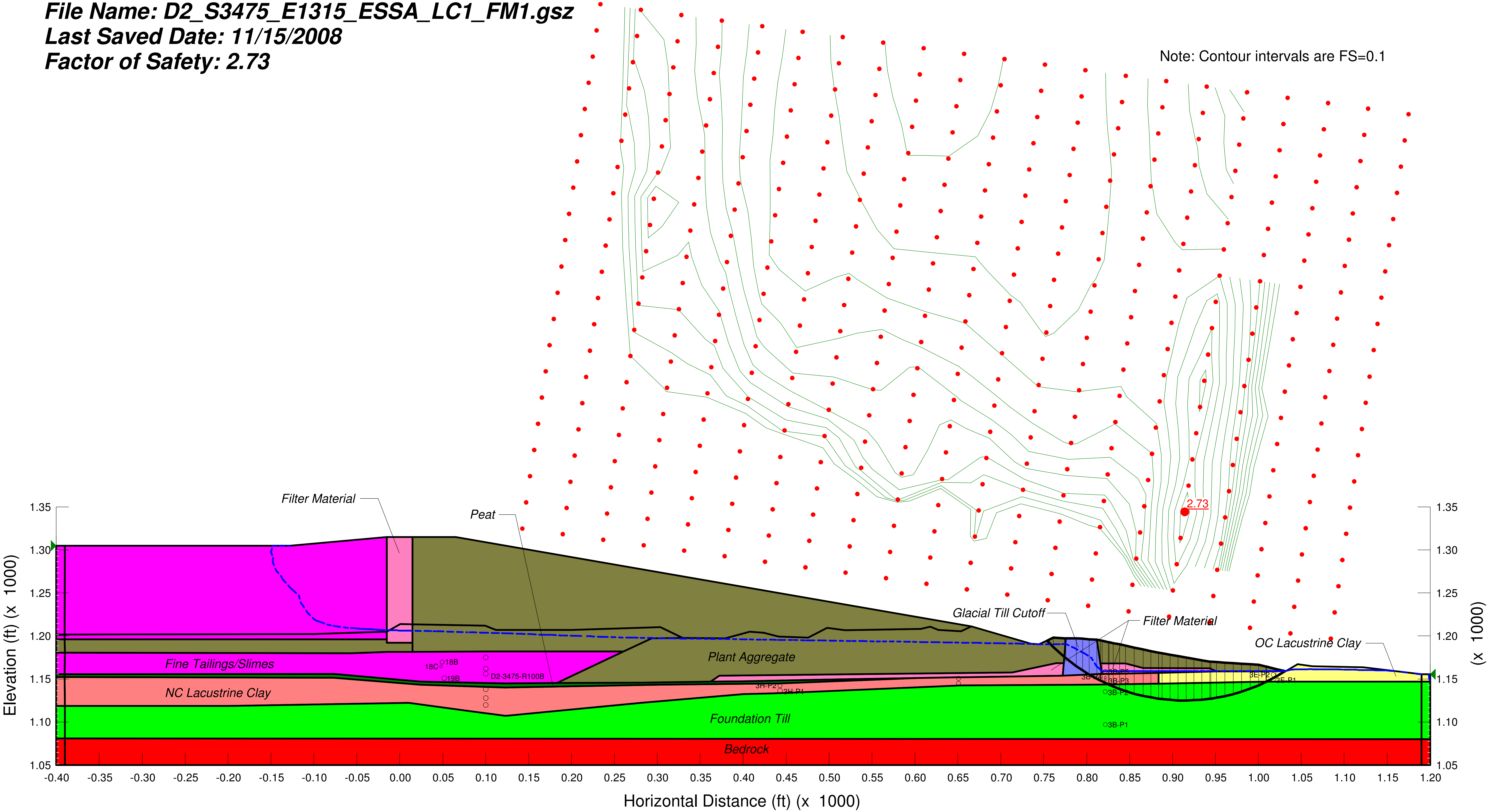
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.2, FM Toe
File Name: D2_S3475_E1315_USSA_LC8_FT2_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.76



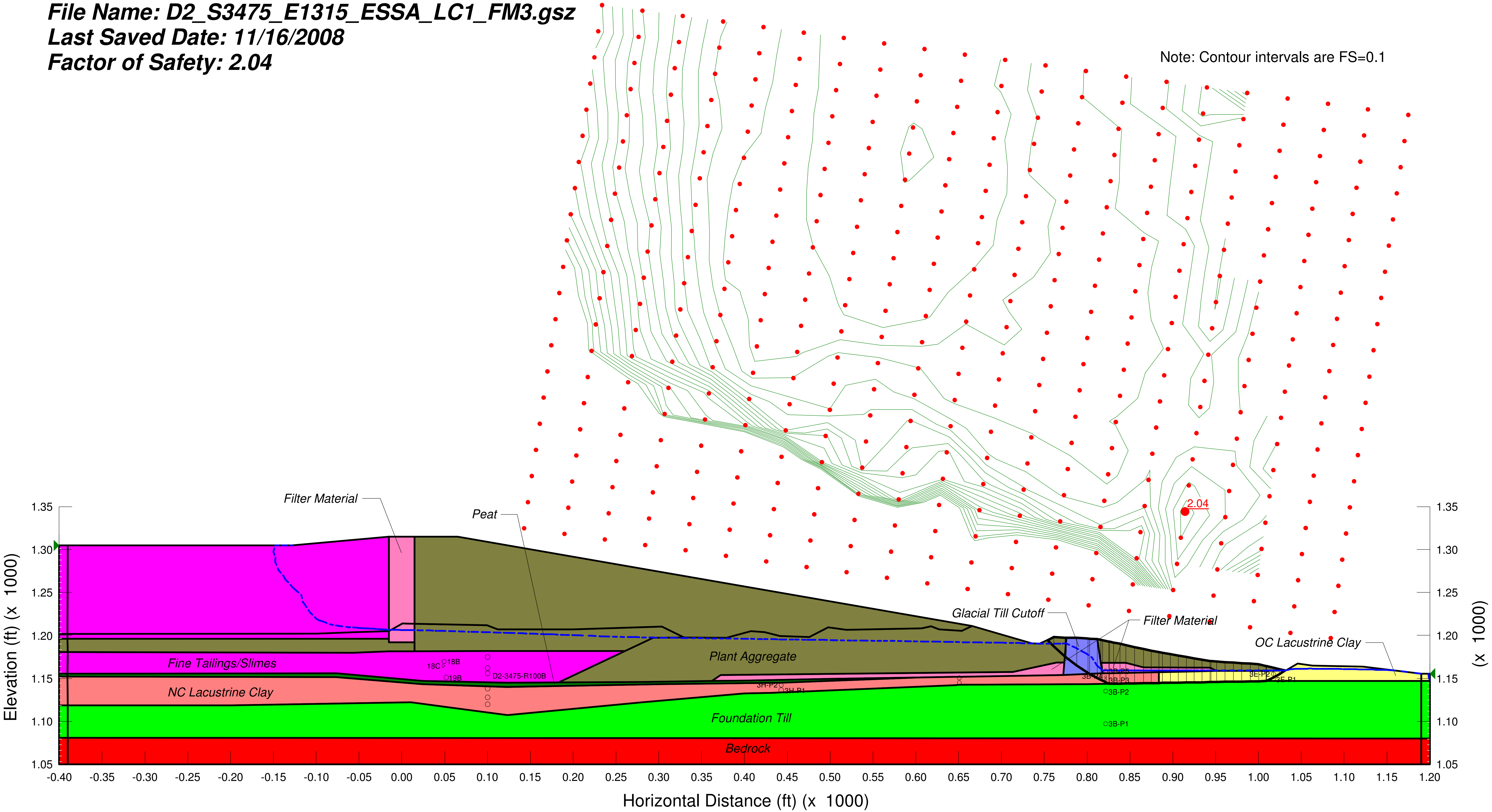
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.2, FM Block
File Name: D2_S3475_E1315_USSA_LC8_FT2_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 2.12



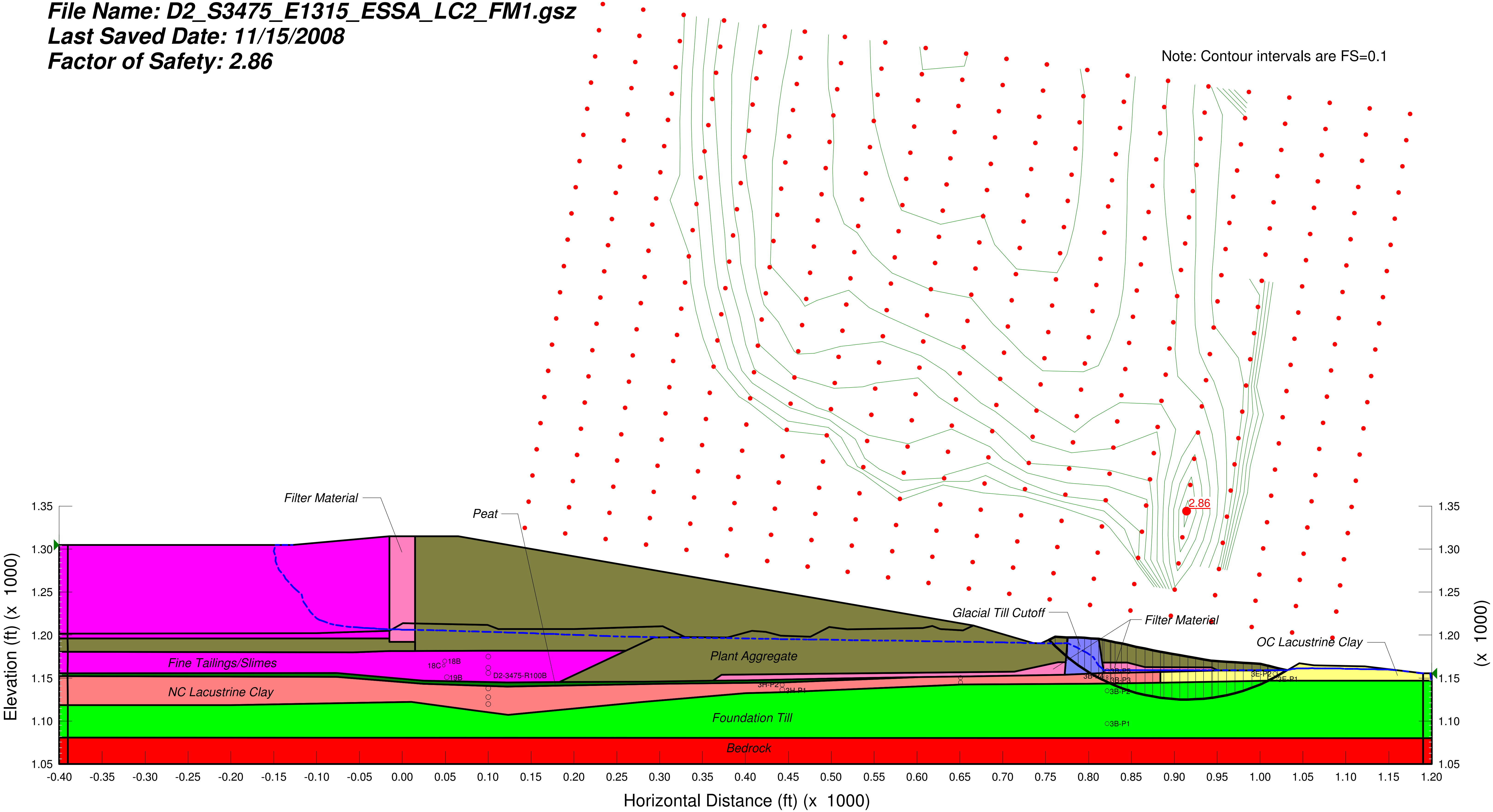
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Low, FM Toe
File Name: D2_S3475_E1315_ESSA_LC1_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.73



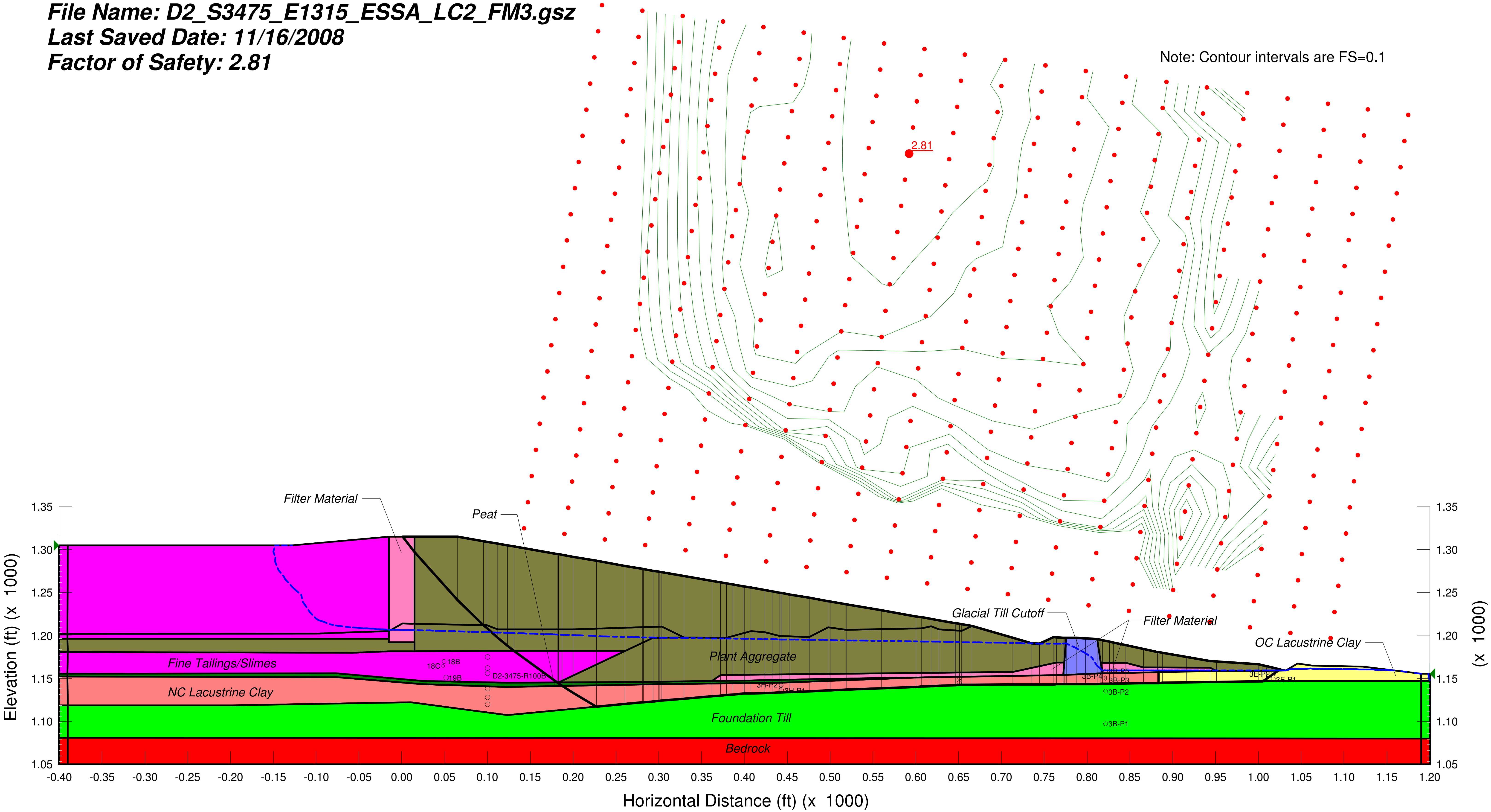
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Low, FM Block
File Name: D2_S3475_E1315_ESSA_LC1_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 2.04



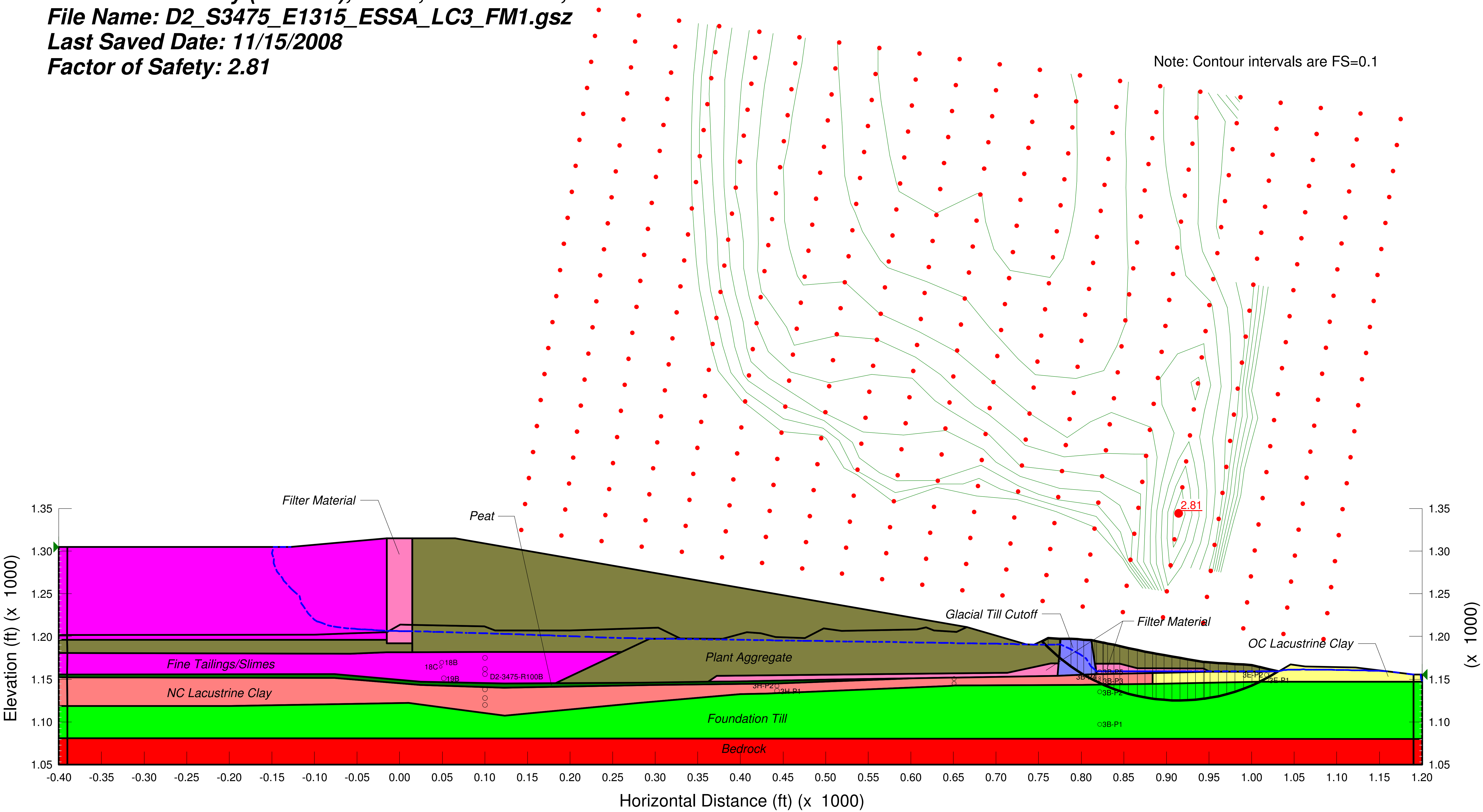
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Toe
File Name: D2_S3475_E1315_ESSA_LC2_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.86



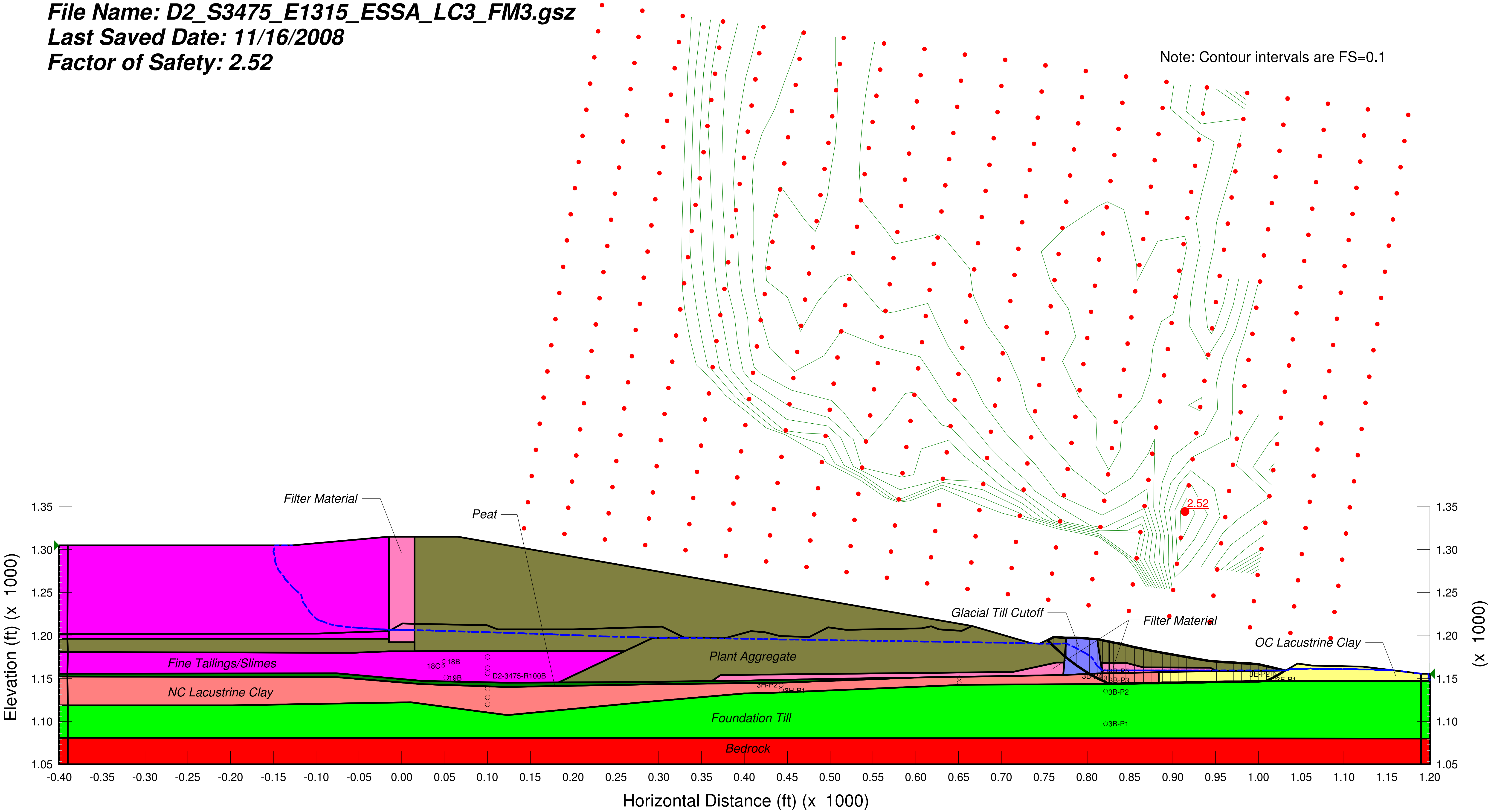
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Block
File Name: D2_S3475_E1315_ESSA_LC2_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 2.81



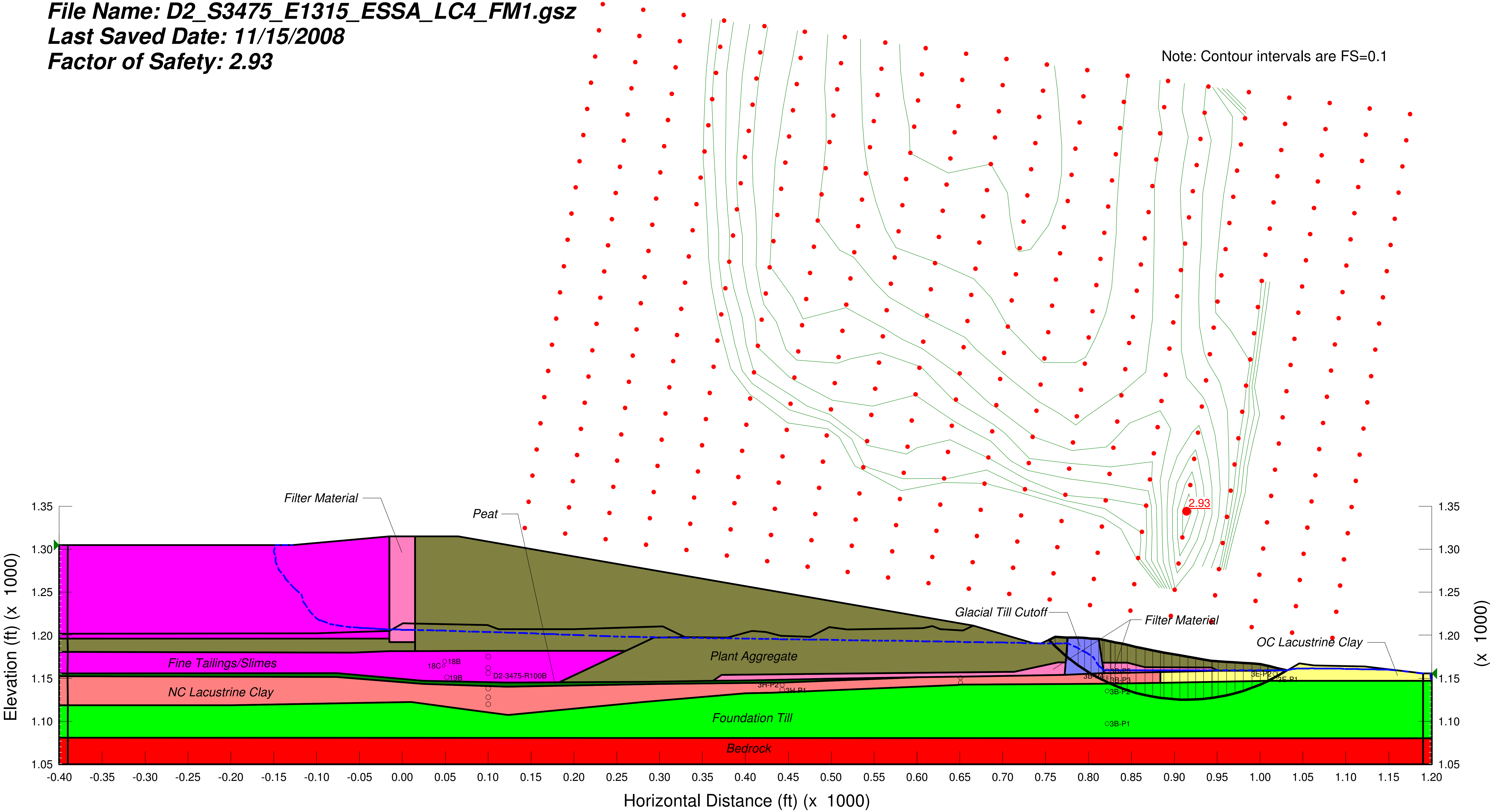
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Low, FM Toe
File Name: D2_S3475_E1315_ESSA_LC3_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.81



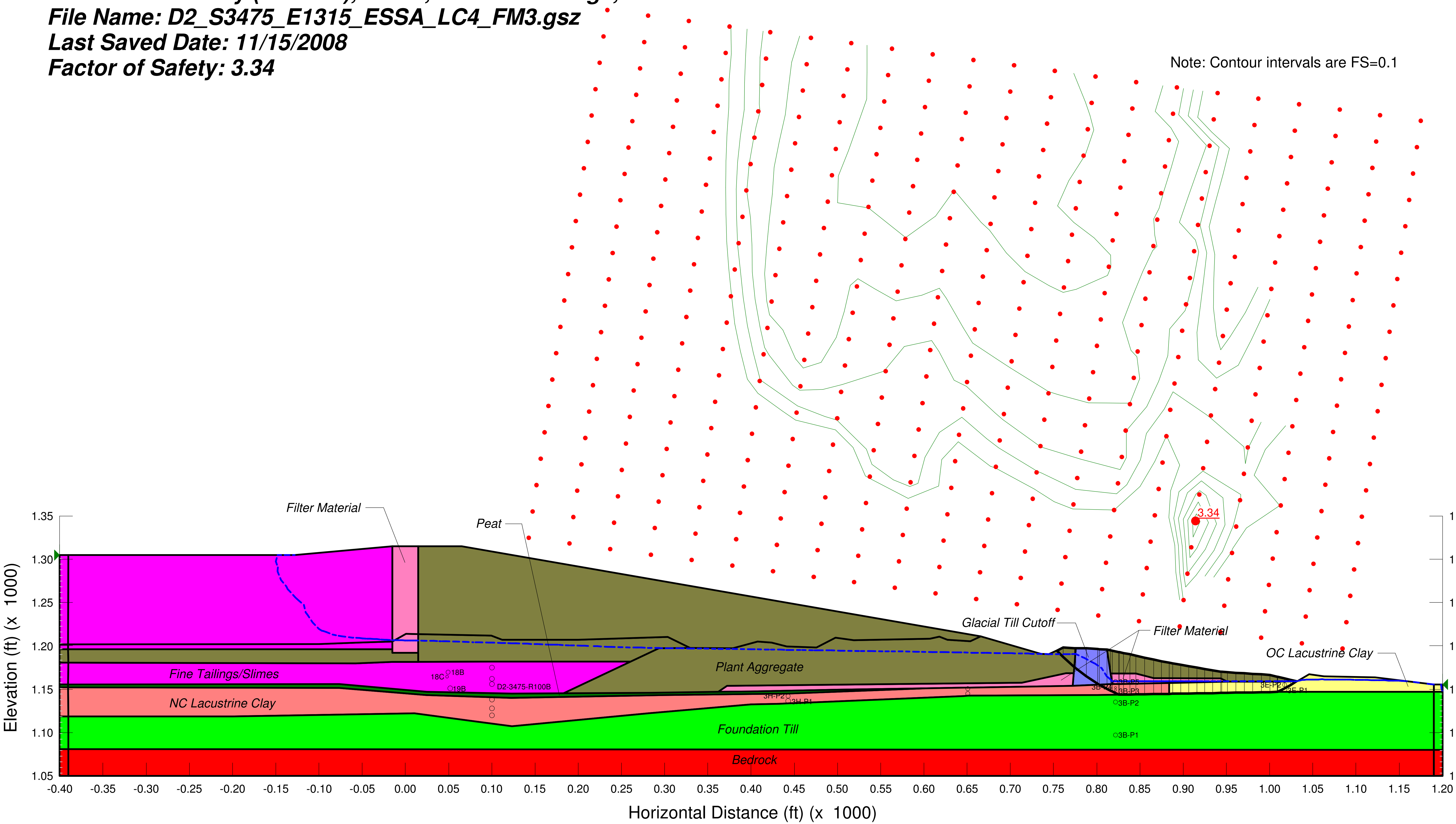
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Low, FM Block
File Name: D2_S3475_E1315_ESSA_LC3_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 2.52

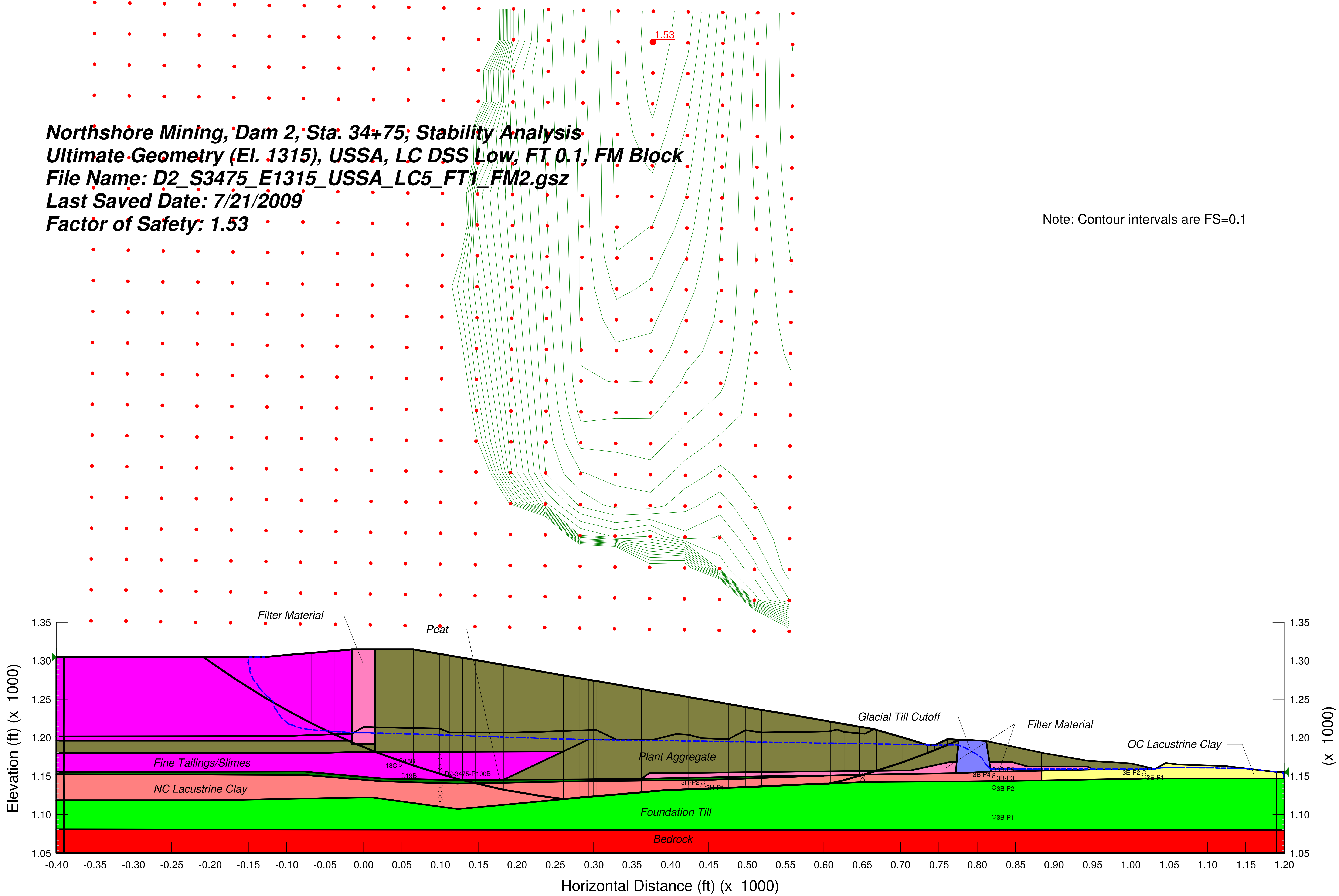


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Toe
File Name: D2_S3475_E1315_ESSA_LC4_FM1.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 2.93



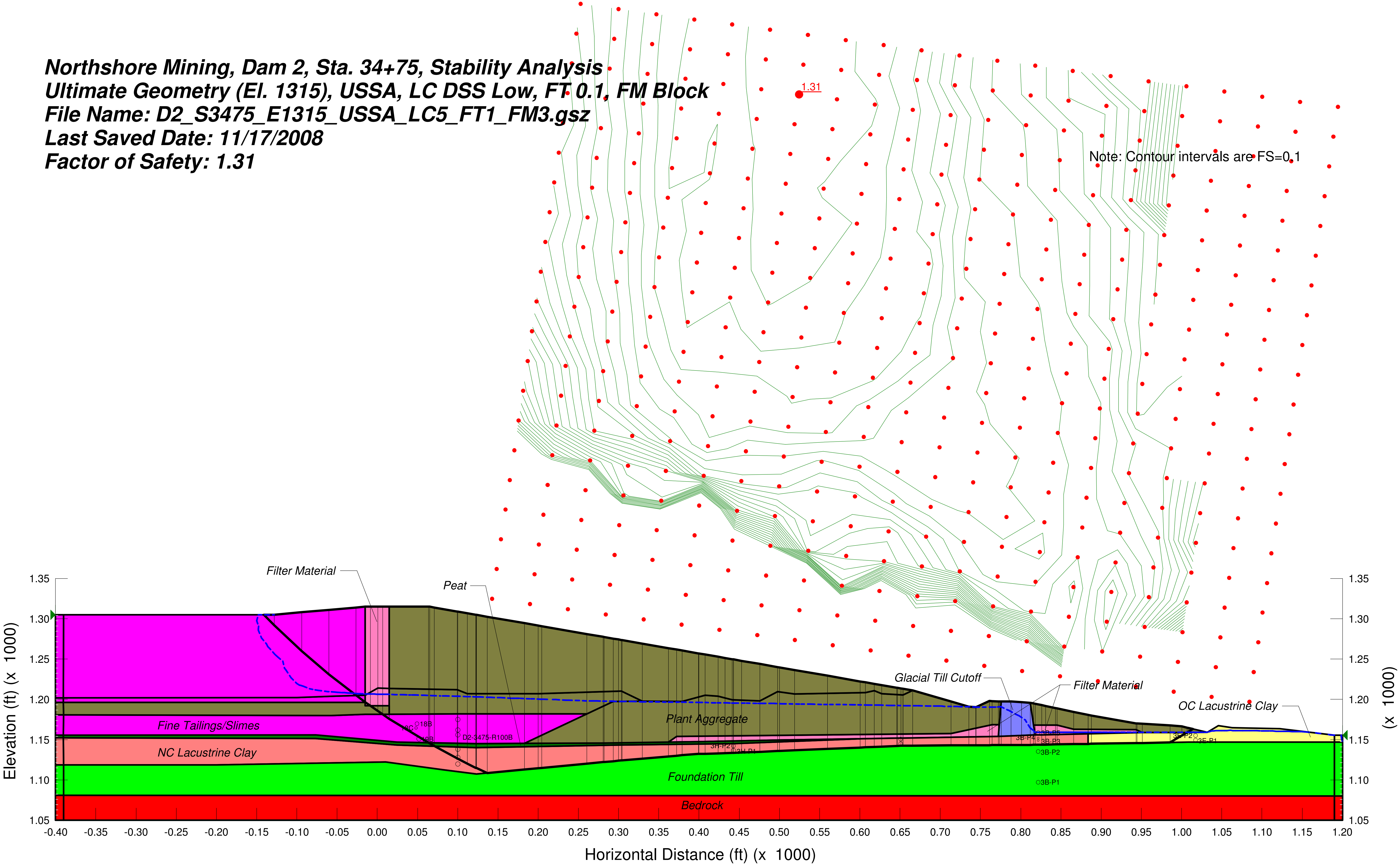
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Block
File Name: D2_S3475_E1315_ESSA_LC4_FM3.gsz
Last Saved Date: 11/15/2008
Factor of Safety: 3.34



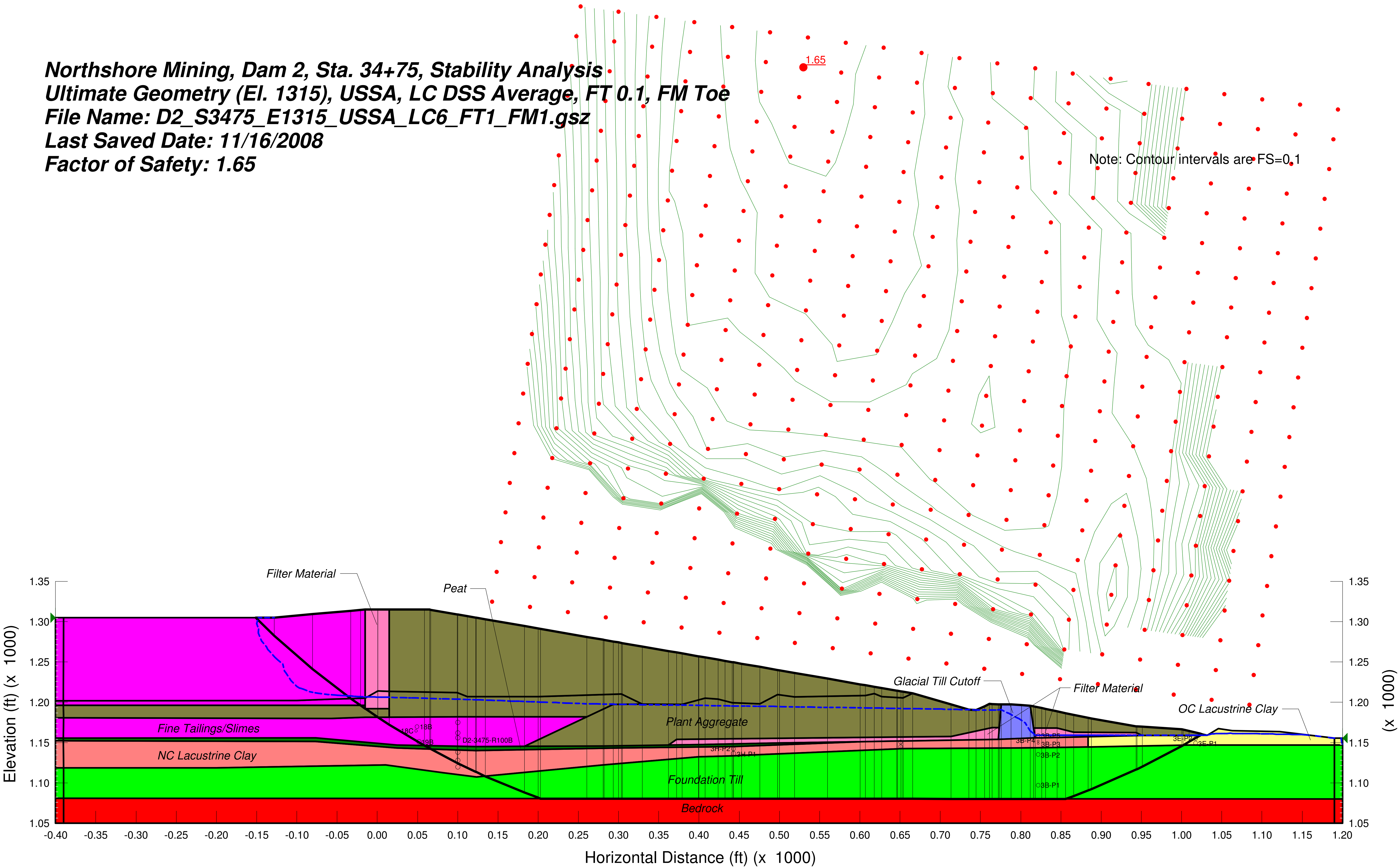


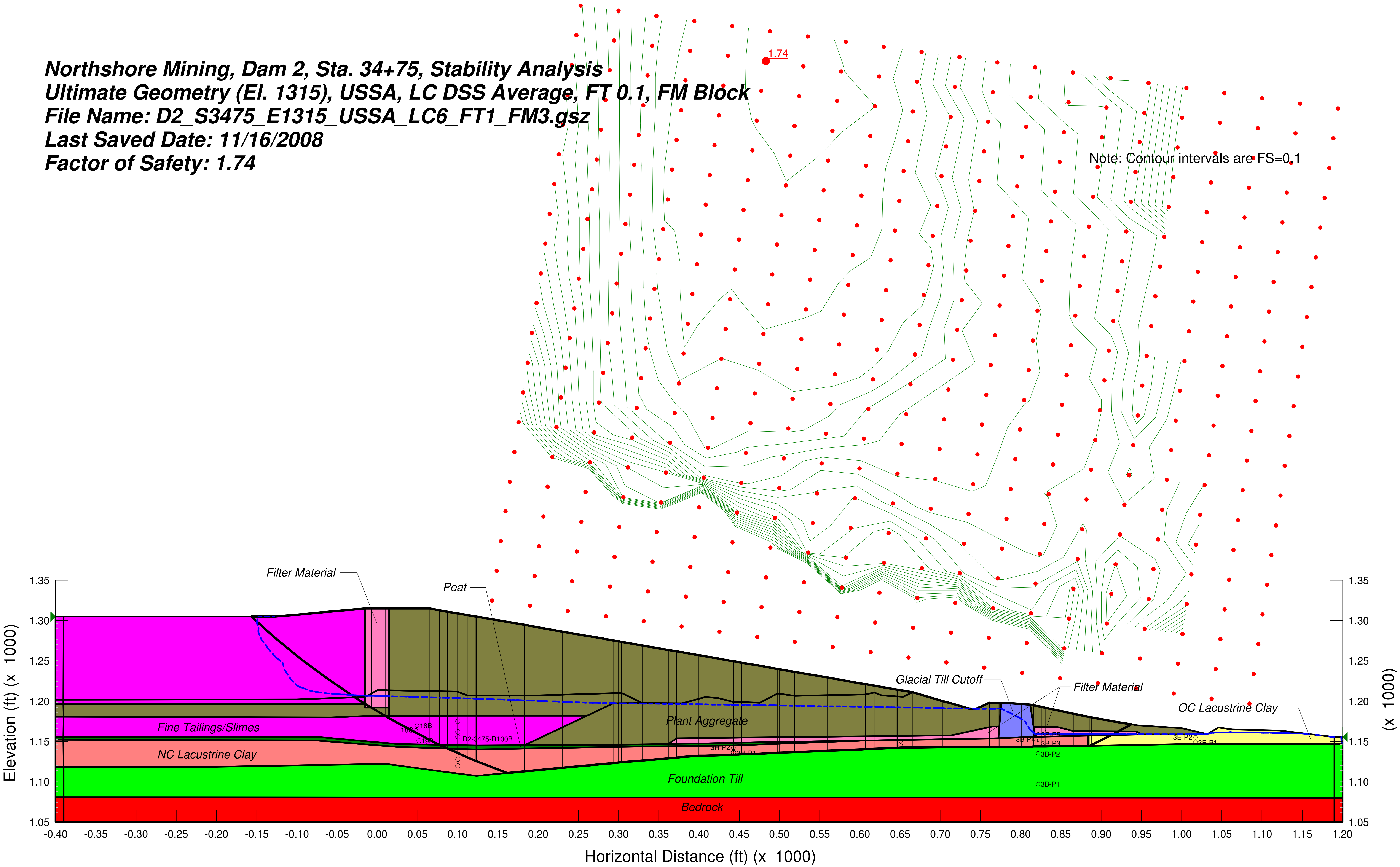
Northshore Mining, Dam 2, Sta. 34+75; Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D2_S3475_E1315_USSA_LC5_FT1_FM2.gsz
Last Saved Date: 7/21/2009
Factor of Safety: 1.53
1.53
Note: Contour intervals are FS=0.1
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Fine Tailings/Slimes
NC Lacustrine Clay
Plant Aggregate
Foundation Till
Bedrock
Elevation (ft) (x 1000)
(x 1000)
Horizontal Distance (ft) (x 1000)

Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FT 0.1, FM Block
File Name: D2_S3475_E1315_USSA_LC5_FT1_FM3.gsz
Last Saved Date: 11/17/2008
Factor of Safety: 1.31



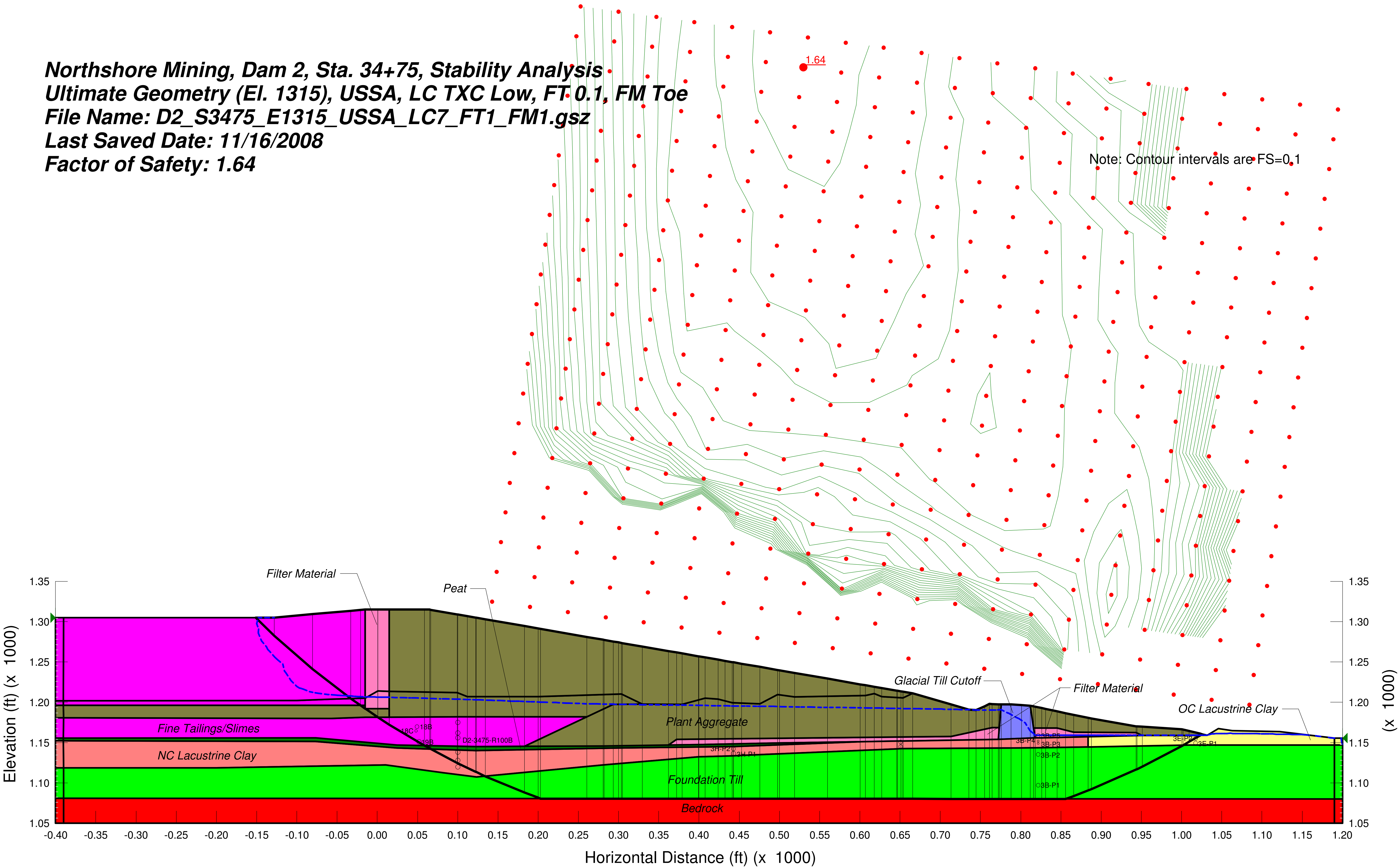
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.1, FM Toe
File Name: D2_S3475_E1315_USSA_LC6_FT1_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.65



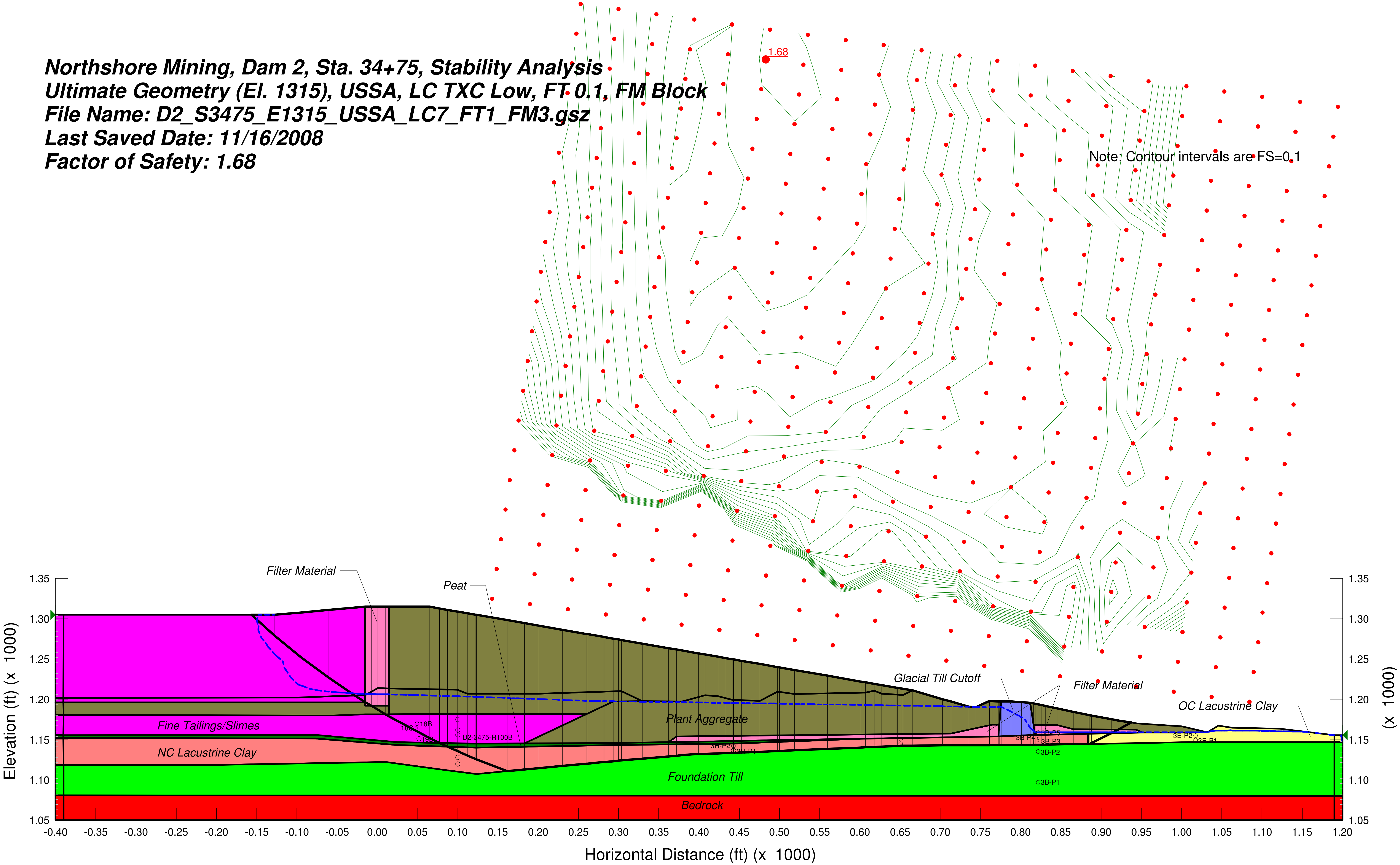


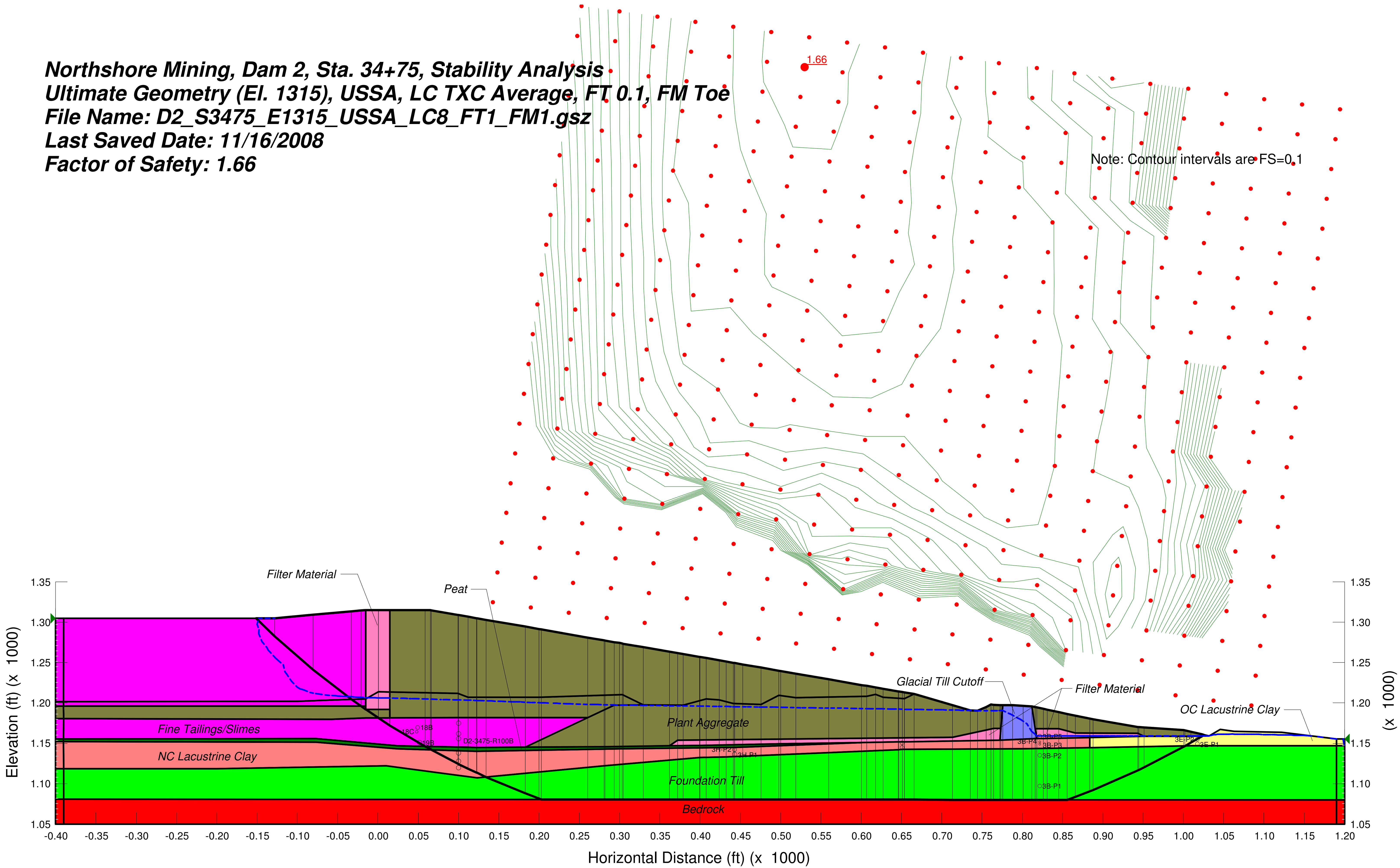
Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FT 0.1, FM Block
File Name: D2_S3475_E1315_USSA_LC6_FT1_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.74
1.74
Note: Contour intervals are FS=0.1
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Plant Aggregate
Fine Tailings/Slimes
NC Lacustrine Clay
Foundation Till
Bedrock
D2-3475-R100B
Elevation (ft) (x 1000)
Horizontal Distance (ft) (x 1000)
(x 1000)

Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.1, FM Toe
File Name: D2_S3475_E1315_USSA_LC7_FT1_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.64

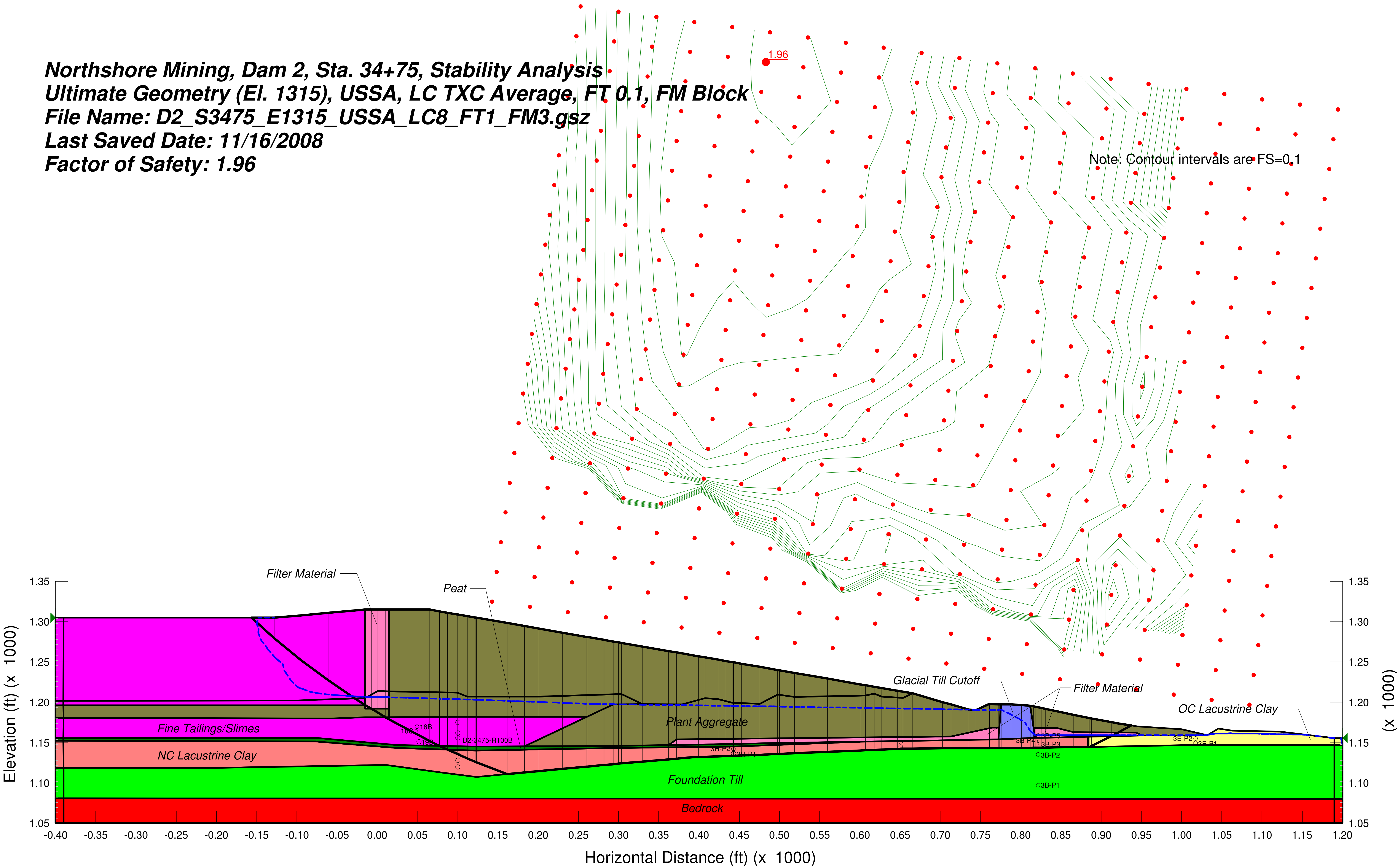


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FT 0.1, FM Block
File Name: D2_S3475_E1315_USSA_LC7_FT1_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.68





Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.1, FM Toe
File Name: D2_S3475_E1315_USSA_LC8_FT1_FM1.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.66
1.66
Note: Contour intervals are FS=0.1
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Fine Tailings/Slimes
NC Lacustrine Clay
Plant Aggregate
Foundation Till
Bedrock
D2-3475-R100B
Elevation (ft) (x 1000)
(x 1000)
Horizontal Distance (ft) (x 1000)
1.35
1.30
1.25
1.20
1.15
1.10
1.05
-0.40 -0.35 -0.30 -0.25 -0.20 -0.15 -0.10 -0.05 0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20


Northshore Mining, Dam 2, Sta. 34+75, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FT 0.1, FM Block
File Name: D2_S3475_E1315_USSA_LC8_FT1_FM3.gsz
Last Saved Date: 11/16/2008
Factor of Safety: 1.96
1.96
Note: Contour intervals are FS=0.1
Filter Material
Peat
Glacial Till Cutoff
Filter Material
OC Lacustrine Clay
Fine Tailings/Slimes
NC Lacustrine Clay
Plant Aggregate
Foundation Till
Bedrock
D2-3475-R100B
3B-P2
3B-P1
Elevation (ft) (x 1000)
(x 1000)
Horizontal Distance (ft) (x 1000)
1.35
1.30
1.25
1.20
1.15
1.10
1.05
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20

Dam 5

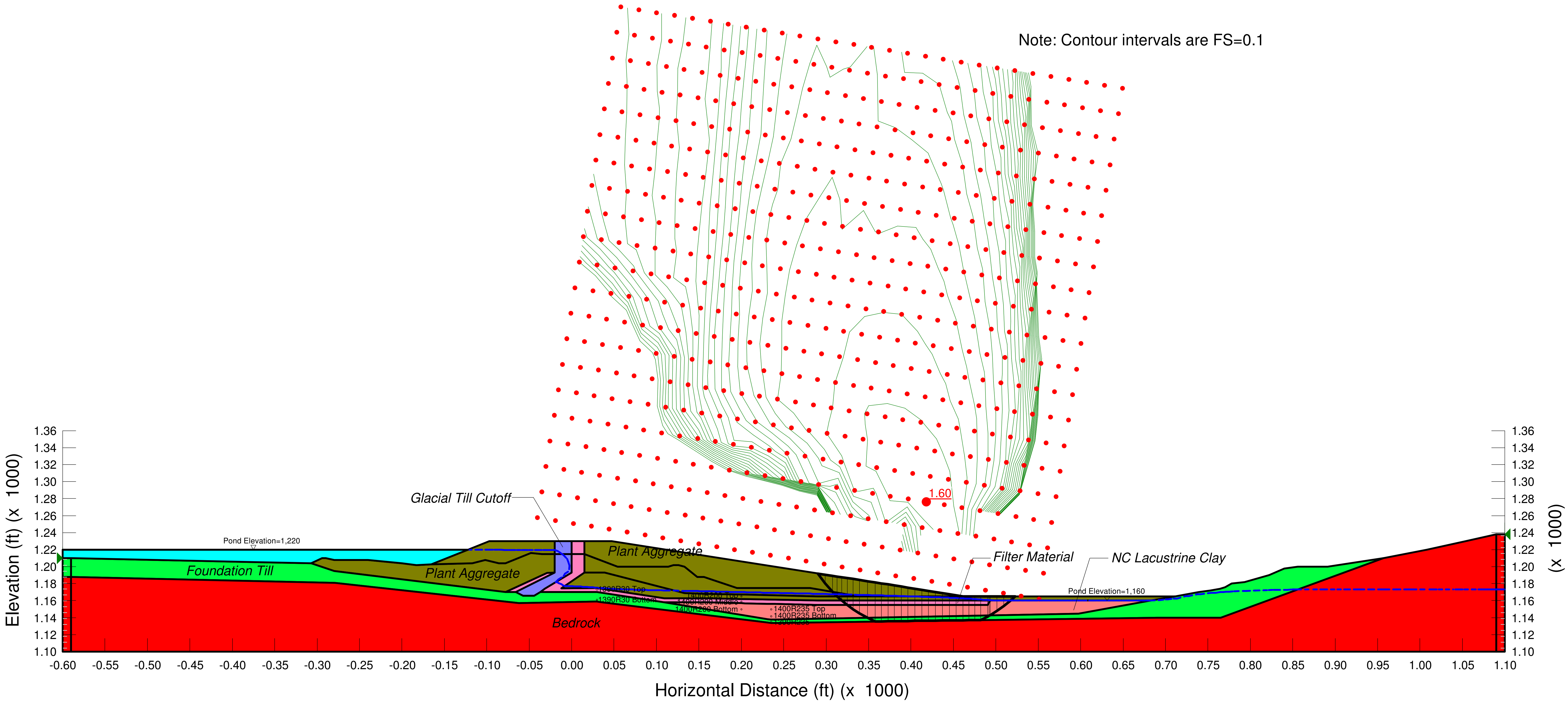
Proposed Geometry El. 1,230 feet

Proposed Geometry El. 1,245 feet

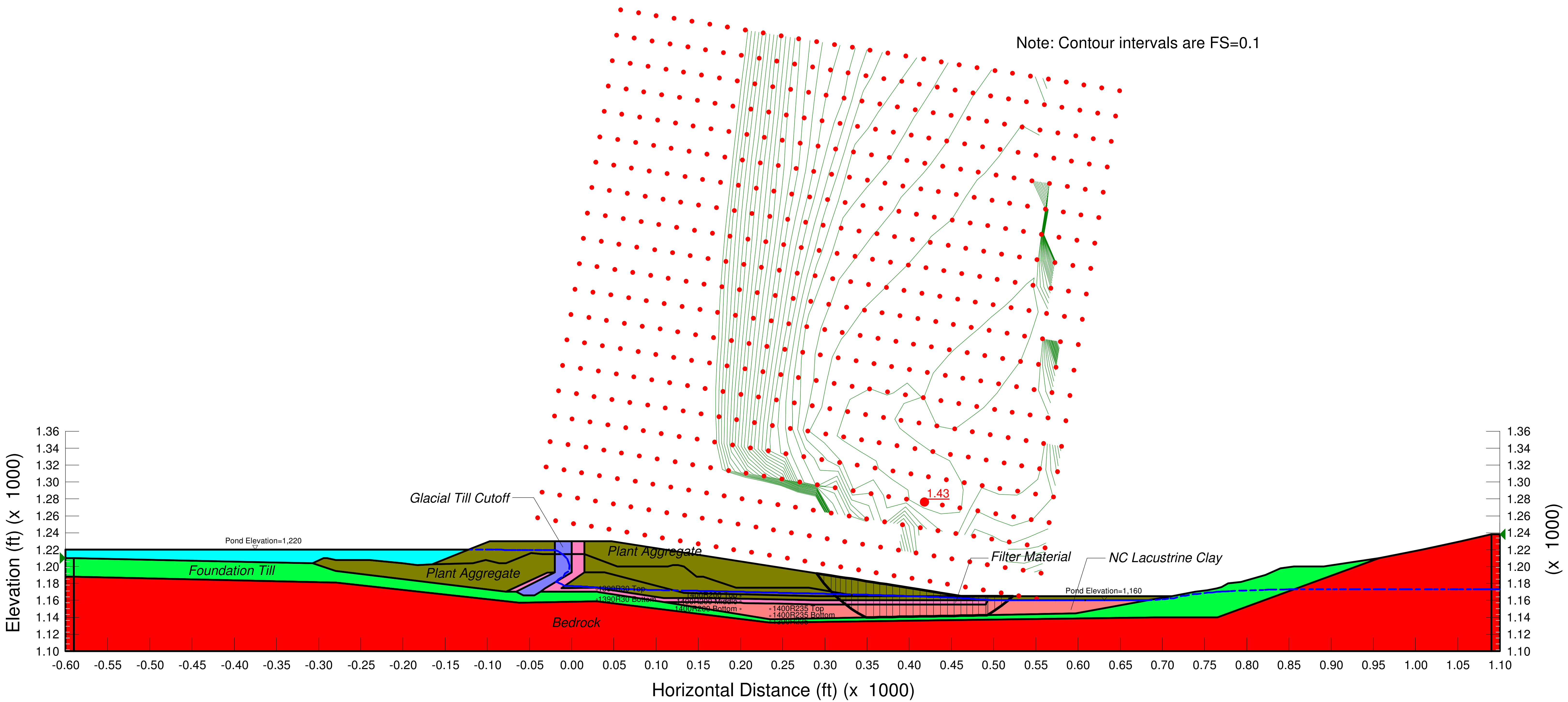
Proposed Geometry El. 1,315 feet

Proposed Geometry El. 1,230 feet

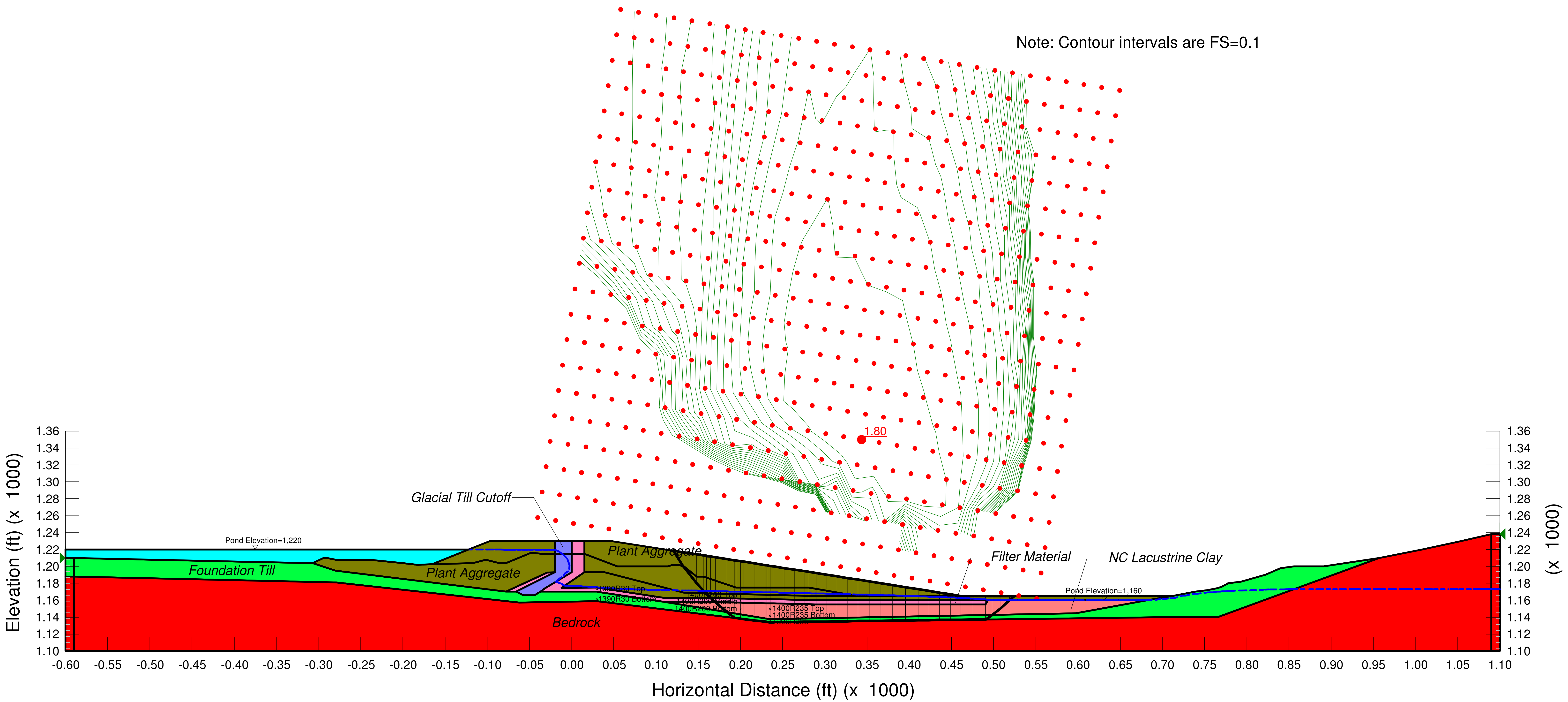
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FM Toe, Low Pond
File Name: D5_S1400_E1230_USSA_LC5_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.60



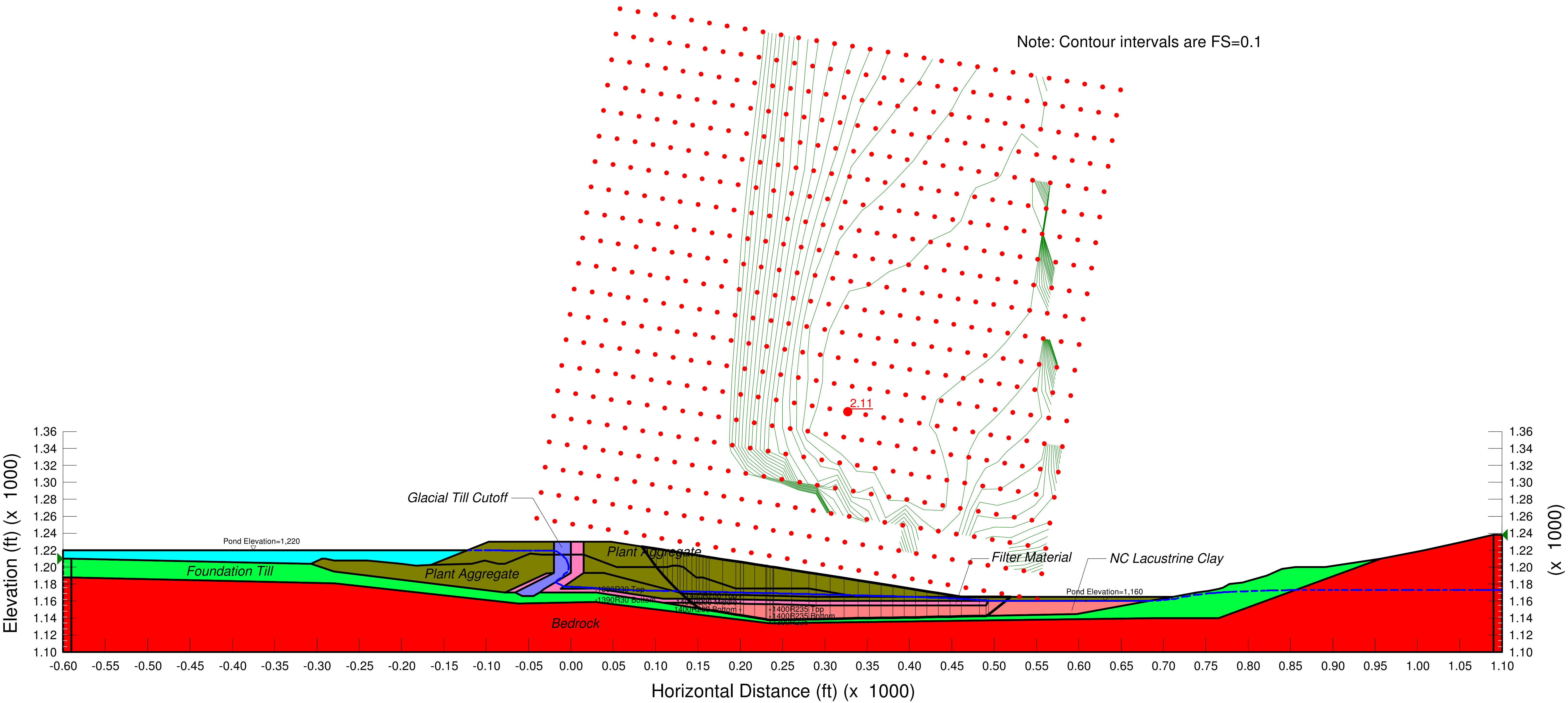
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FM Block, Low Pond
File Name: D5_S1400_E1230_USSA_LC5_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.43



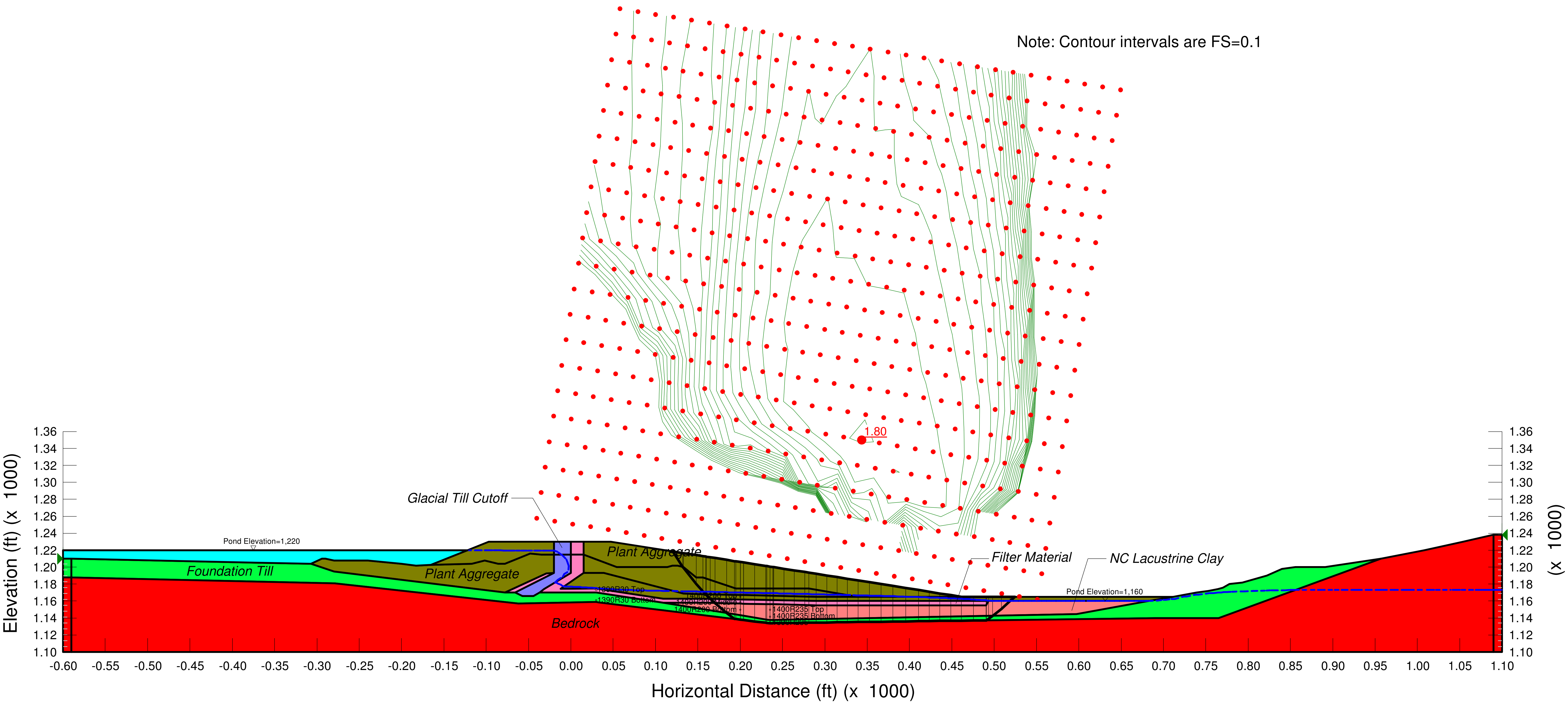
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FM Toe, Low Pond
_File Name: D5_S1400_E1230_USSA_LC6_FM1_Low.gsz_
Last Saved Date: 8/21/2008
Factor of Safety: 1.80



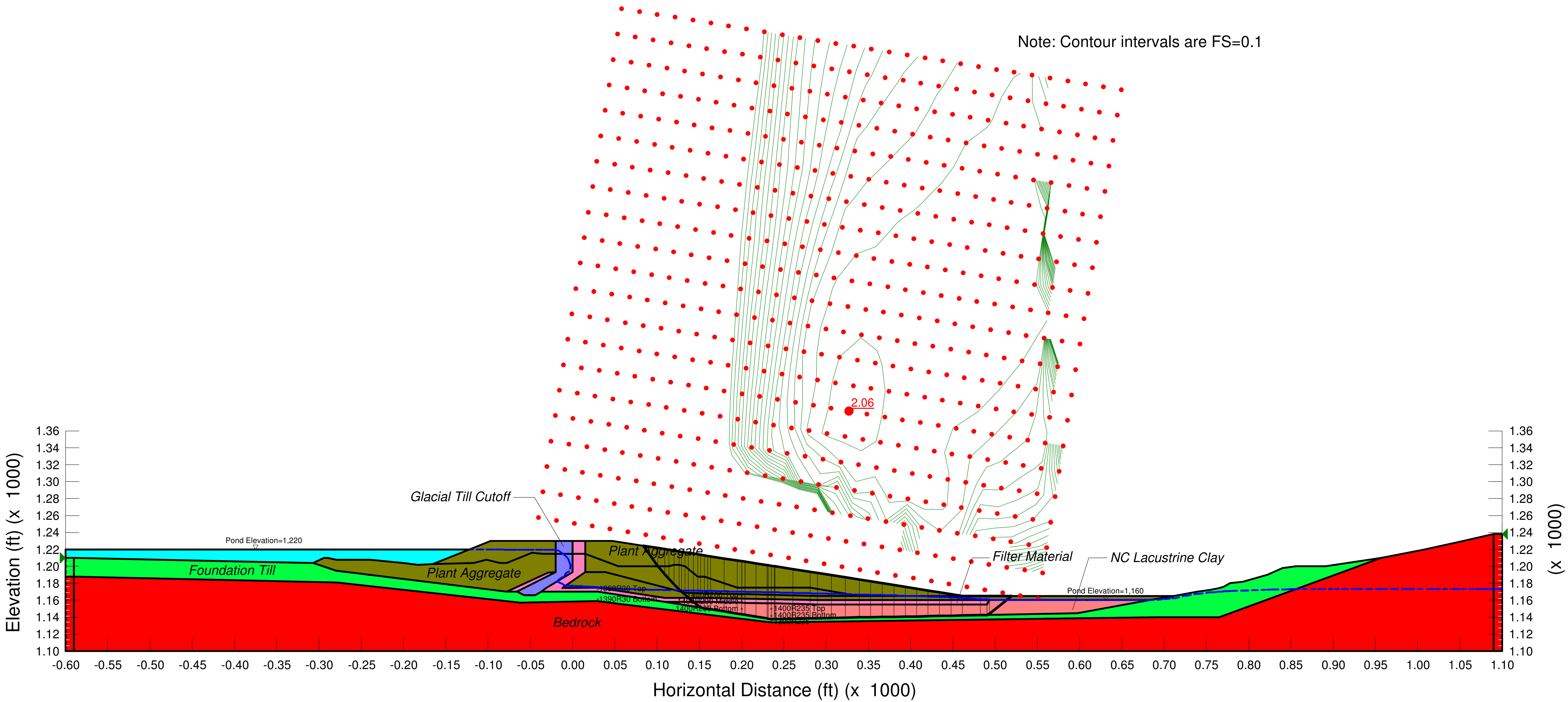
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FM Block, Low Pond
File Name: D5_S1400_E1230_USSA_LC6_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.11



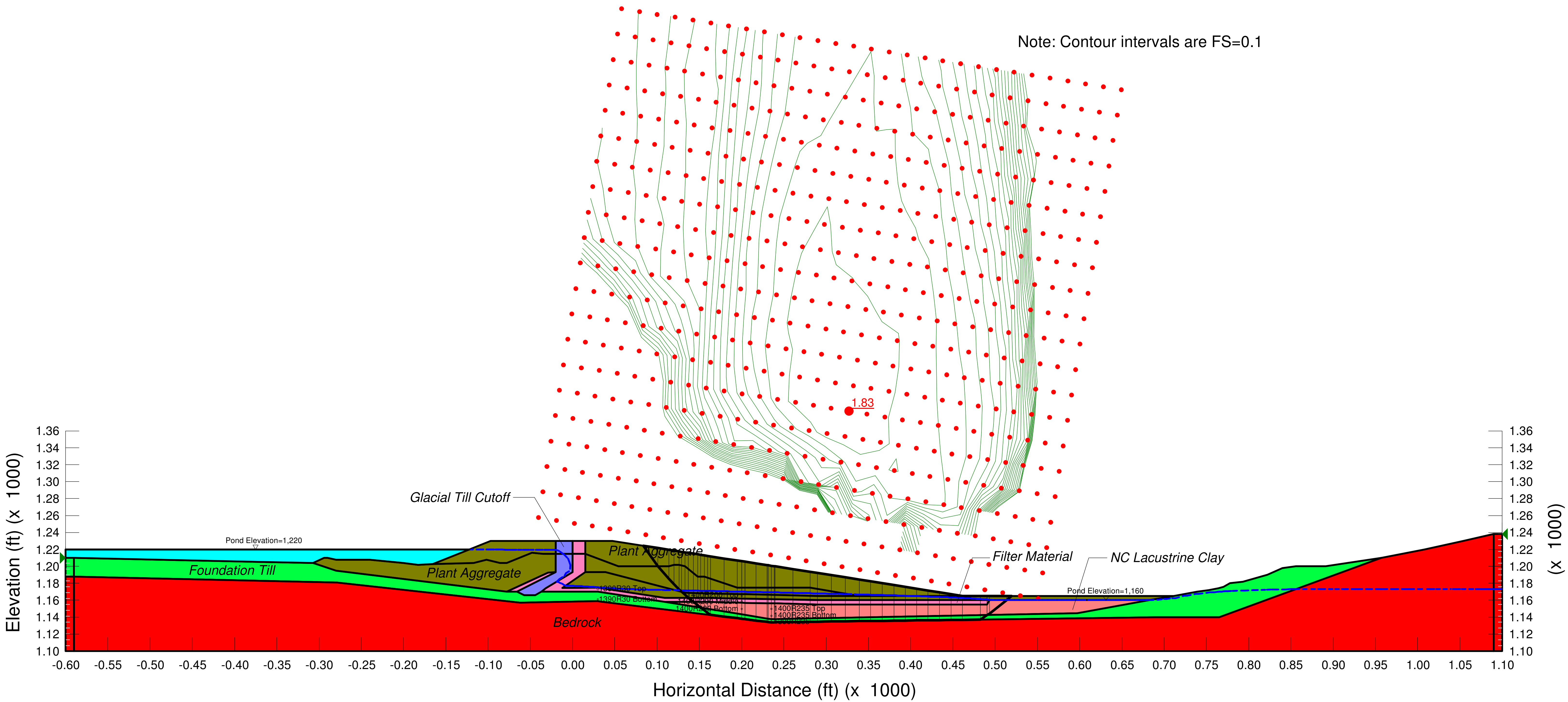
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FM Toe, Low Pond
File Name: D5_S1400_E1230_USSA_LC7_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.80



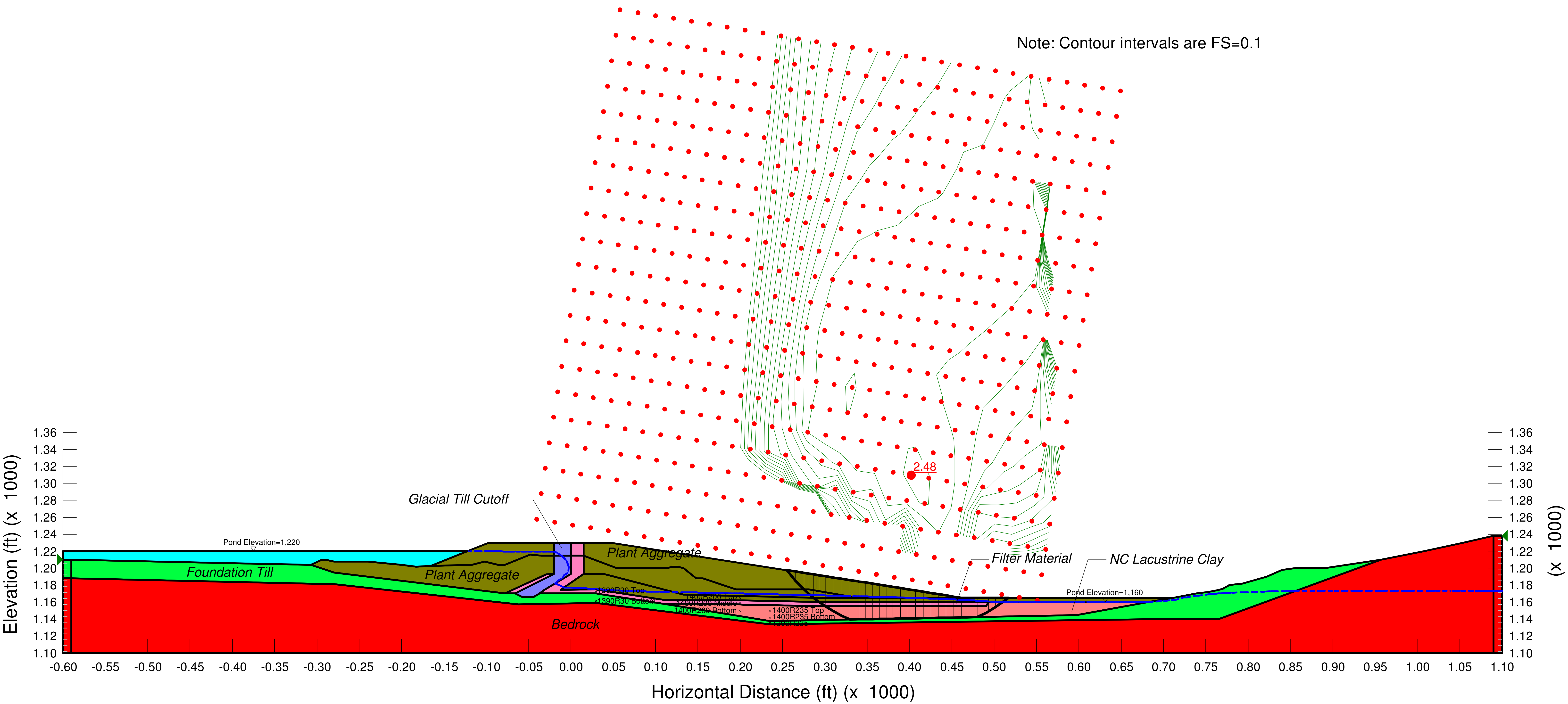
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FM Block, Low Pond
File Name: D5_S1400_E1230_USSA_LC7_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.06



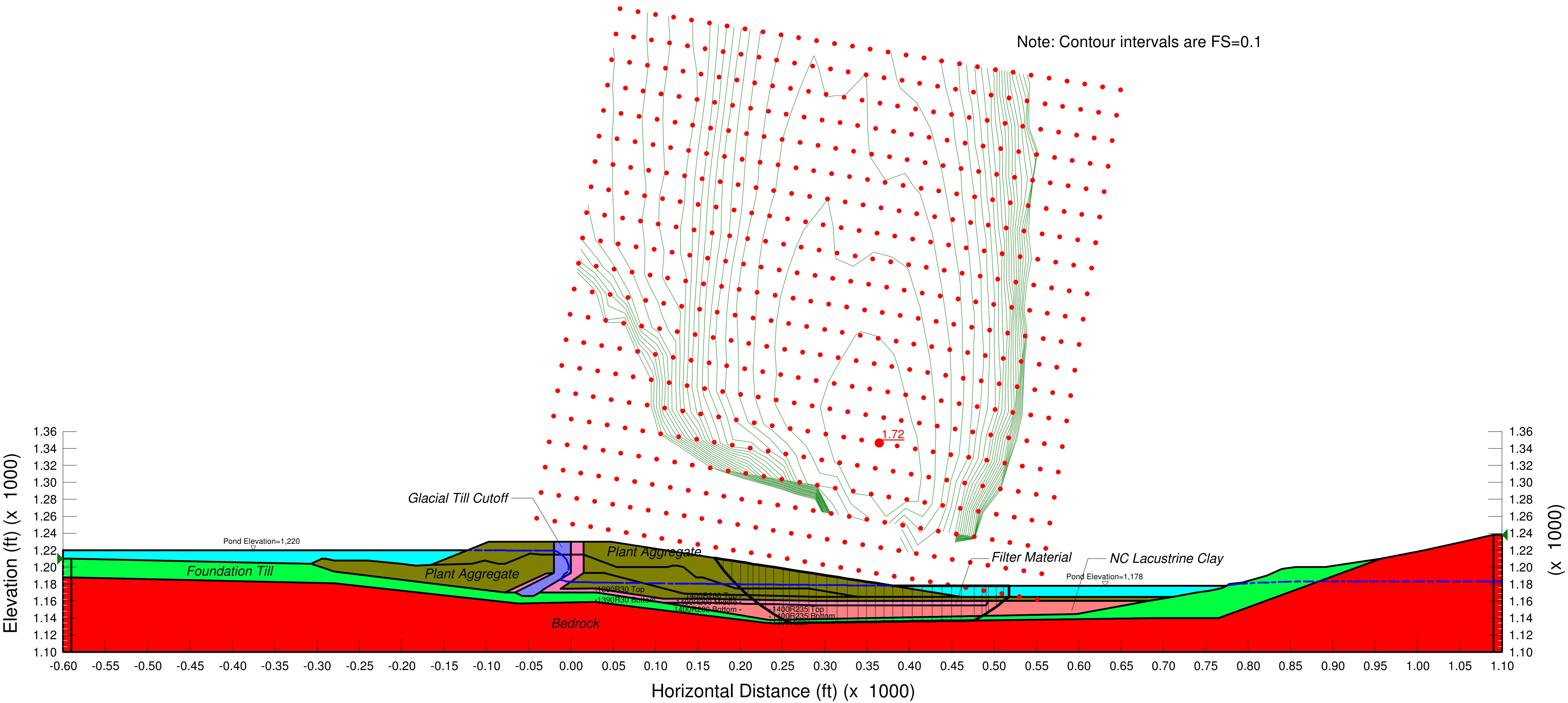
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FM Toe, Low Pond
File Name: D5_S1400_E1230_USSA_LC8_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.83



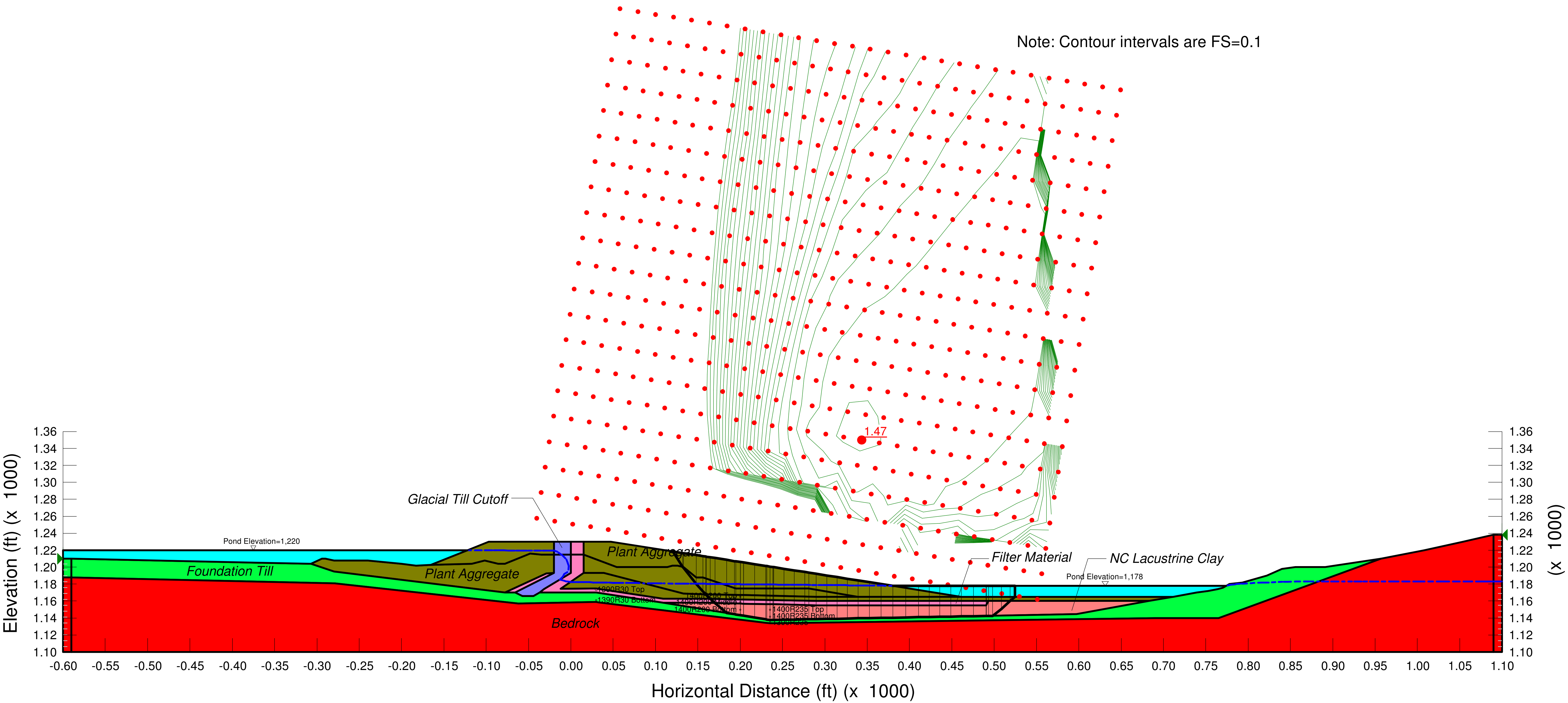
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FM Block, Low Pond
File Name: D5_S1400_E1230_USSA_LC8_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.48



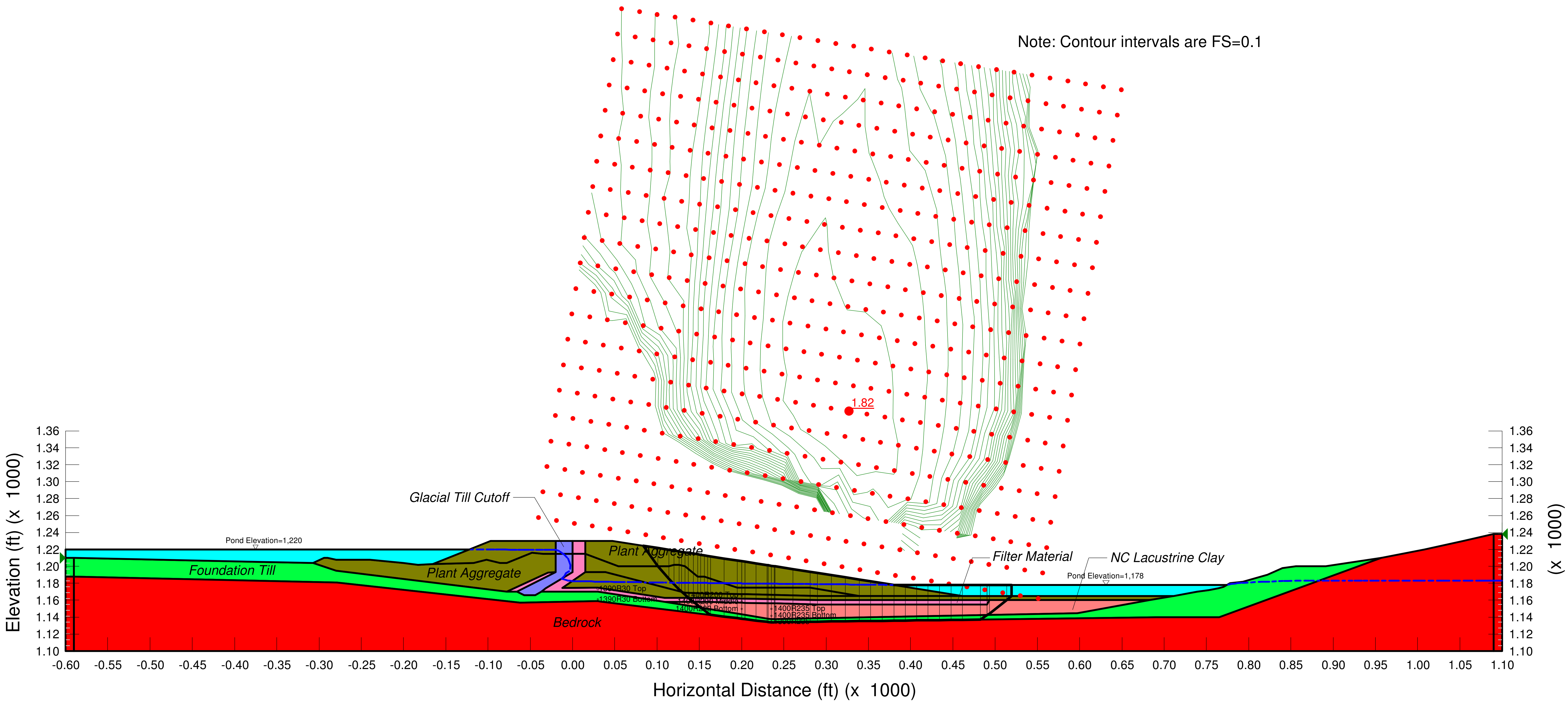
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FM Toe, High Pond
File Name: D5_S1400_E1230_USSA_LC5_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.72



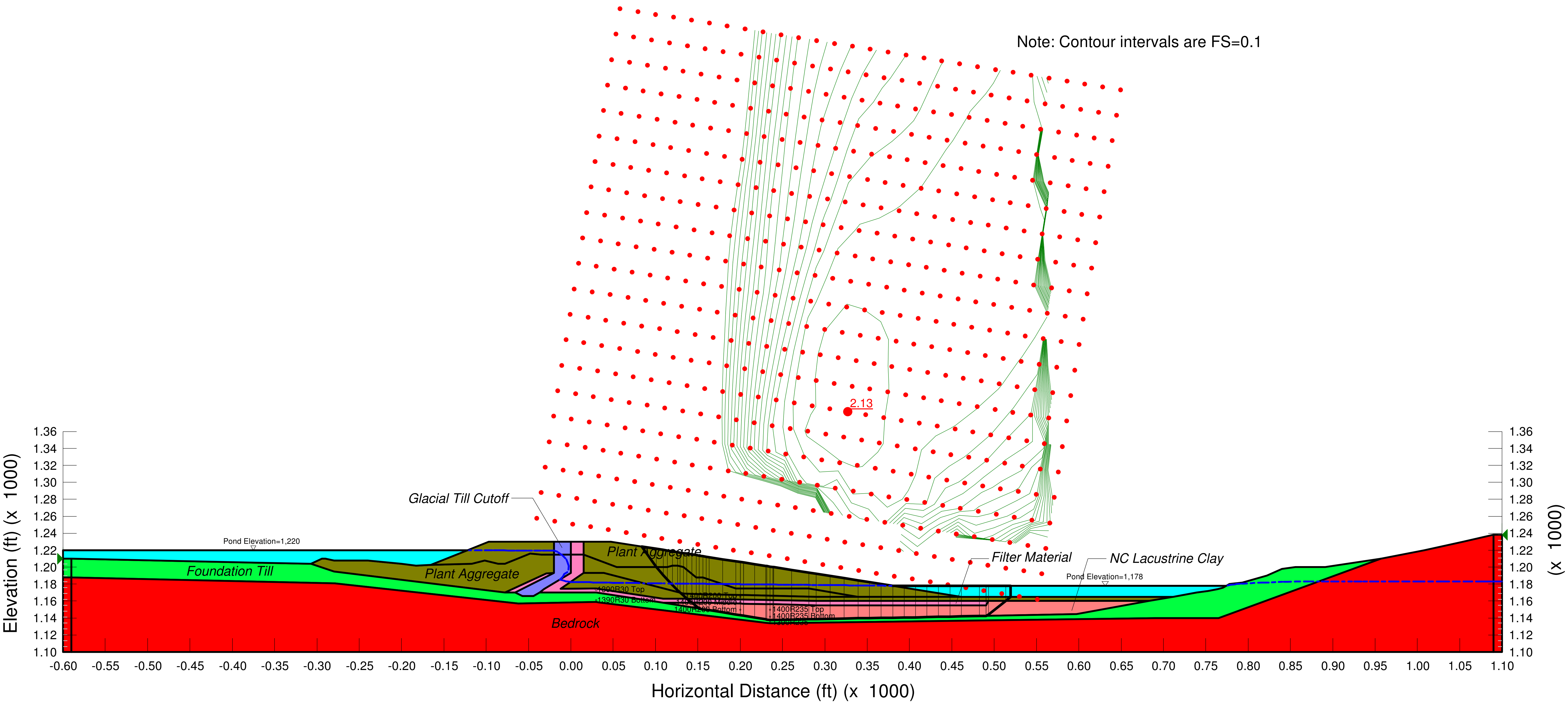
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Low, FM Block, High Pond
File Name: D5_S1400_E1230_USSA_LC5_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.47



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FM Toe, High Pond
File Name: D5_S1400_E1230_USSA_LC6_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.82



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC DSS Average, FM Block, High Pond
File Name: D5_S1400_E1230_USSA_LC6_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.13



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FM Toe, High Pond
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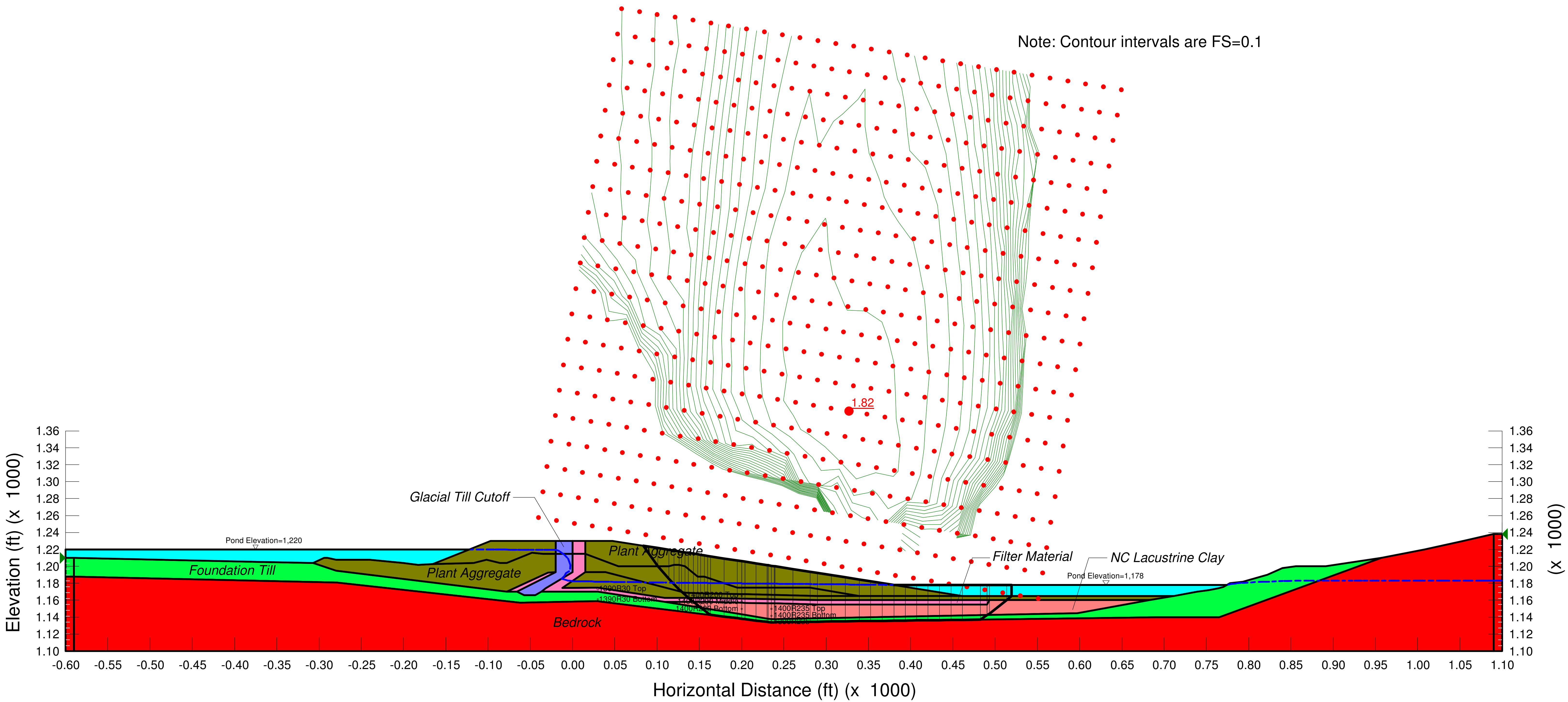
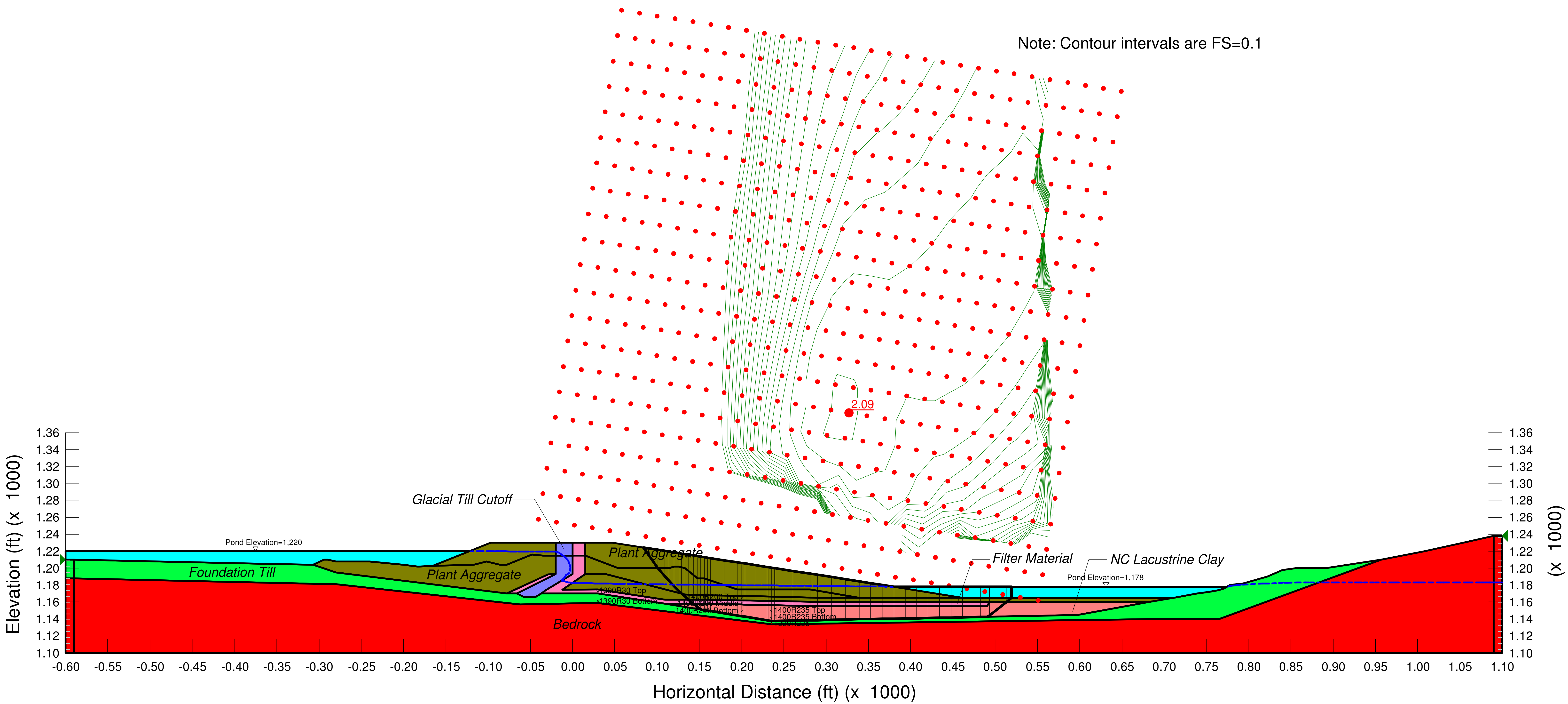
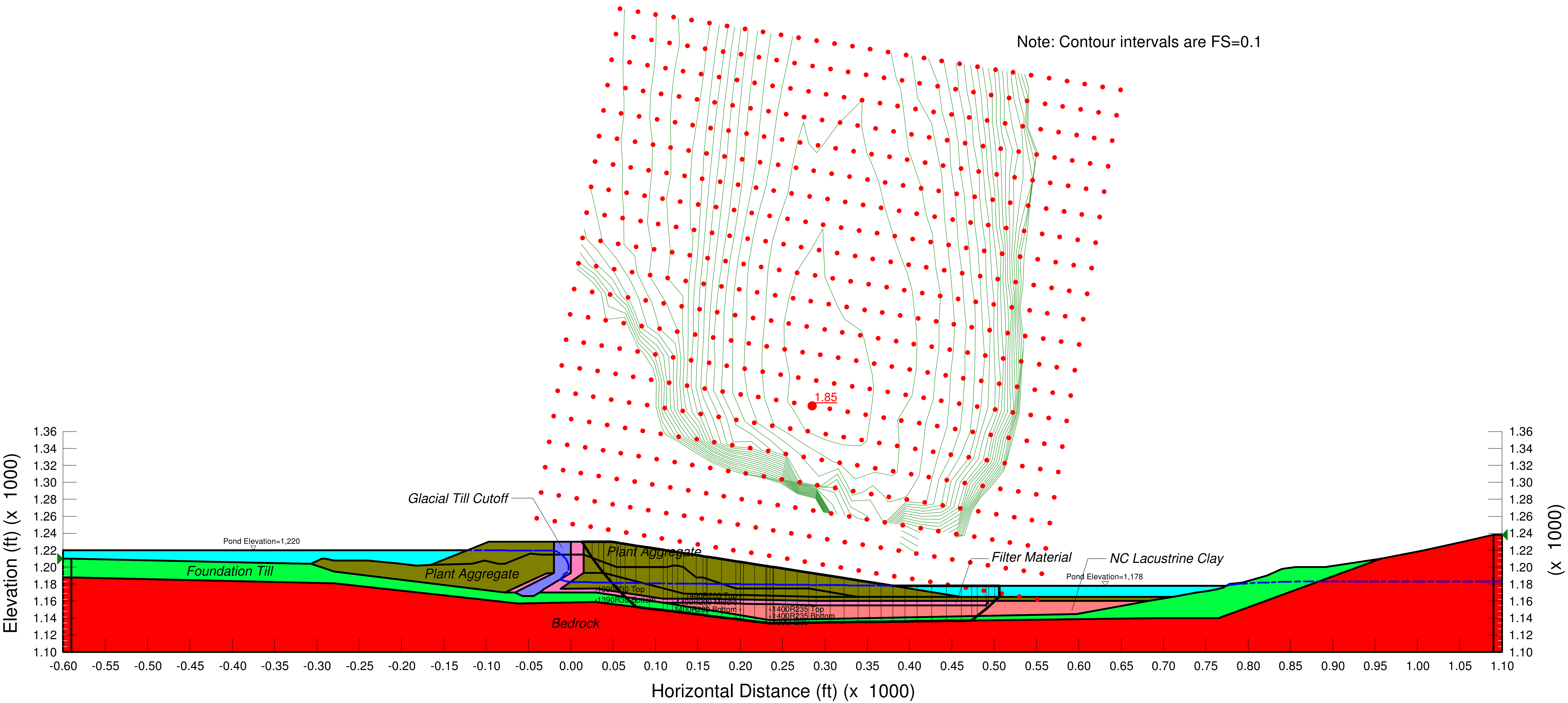
Last Saved Date: 8/21/2008
Factor of Safety: 1.82



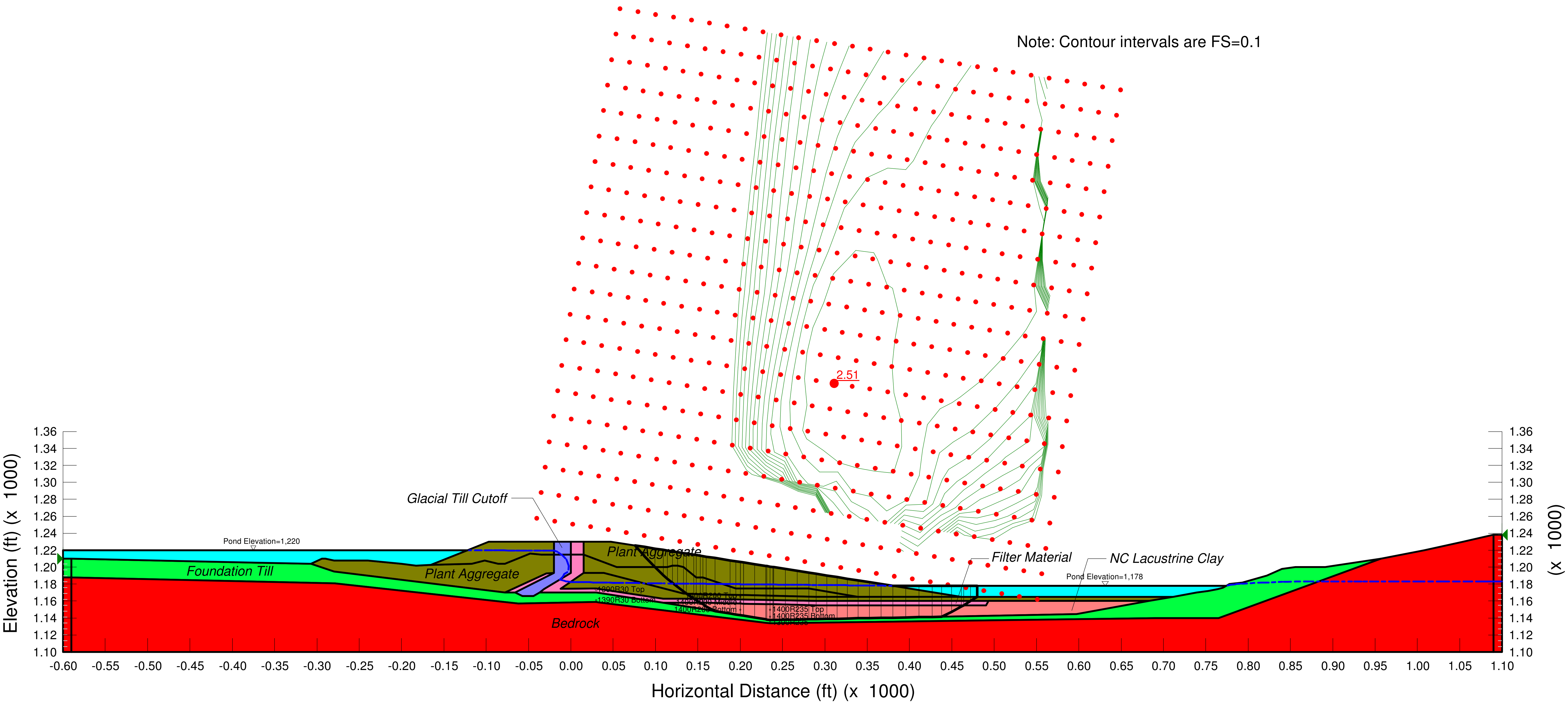
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Low, FM Block, High Pond
File Name: D5_S1400_E1230_USSA_LC7_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.09



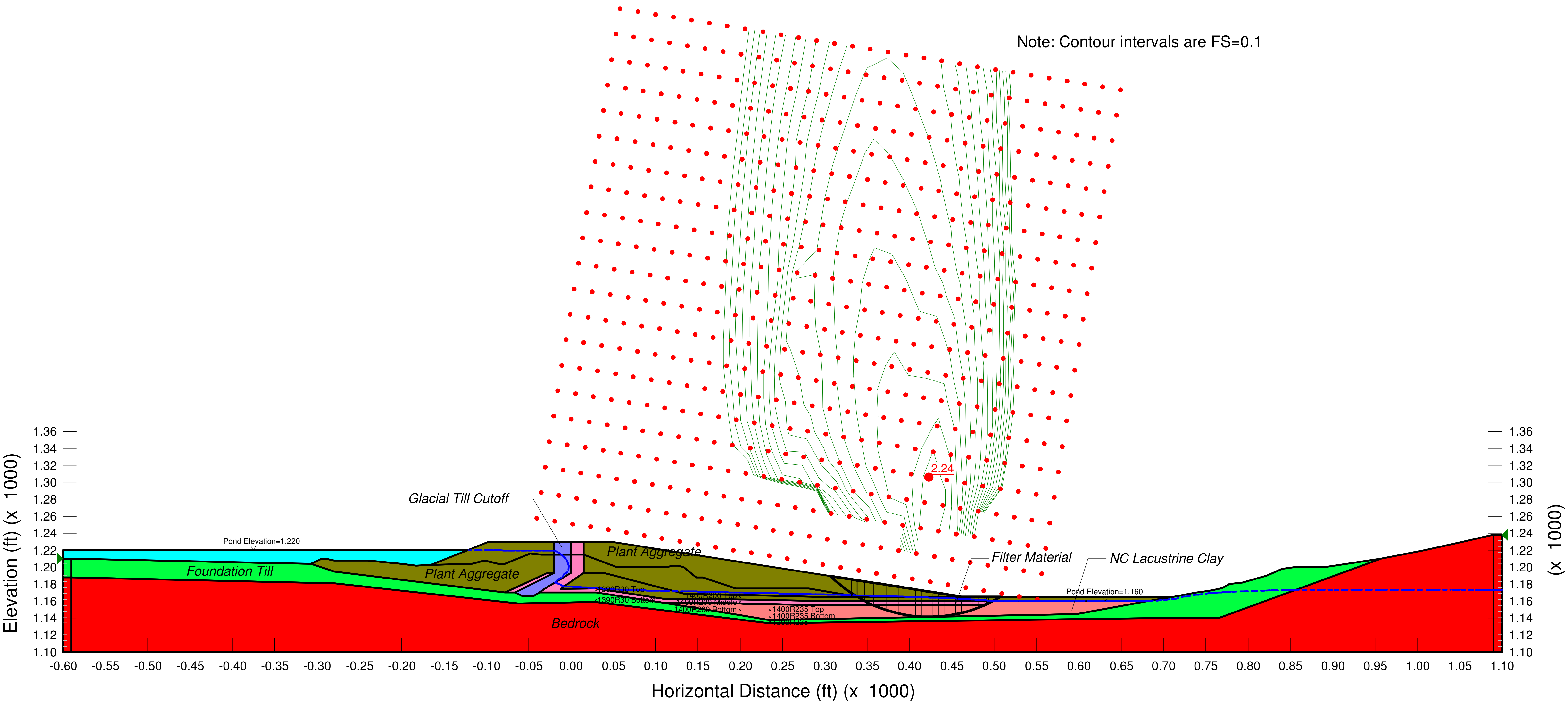
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FM Toe, High Pond
File Name: D5_S1400_E1230_USSA_LC8_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.85



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), USSA, LC TXC Average, FM Block, High Pond
File Name: D5_S1400_E1230_USSA_LC8_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.51



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Toe, Low Pond
File Name: D5_S1400_E1230_ESSA_LC1_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.24



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Block, Low Pond
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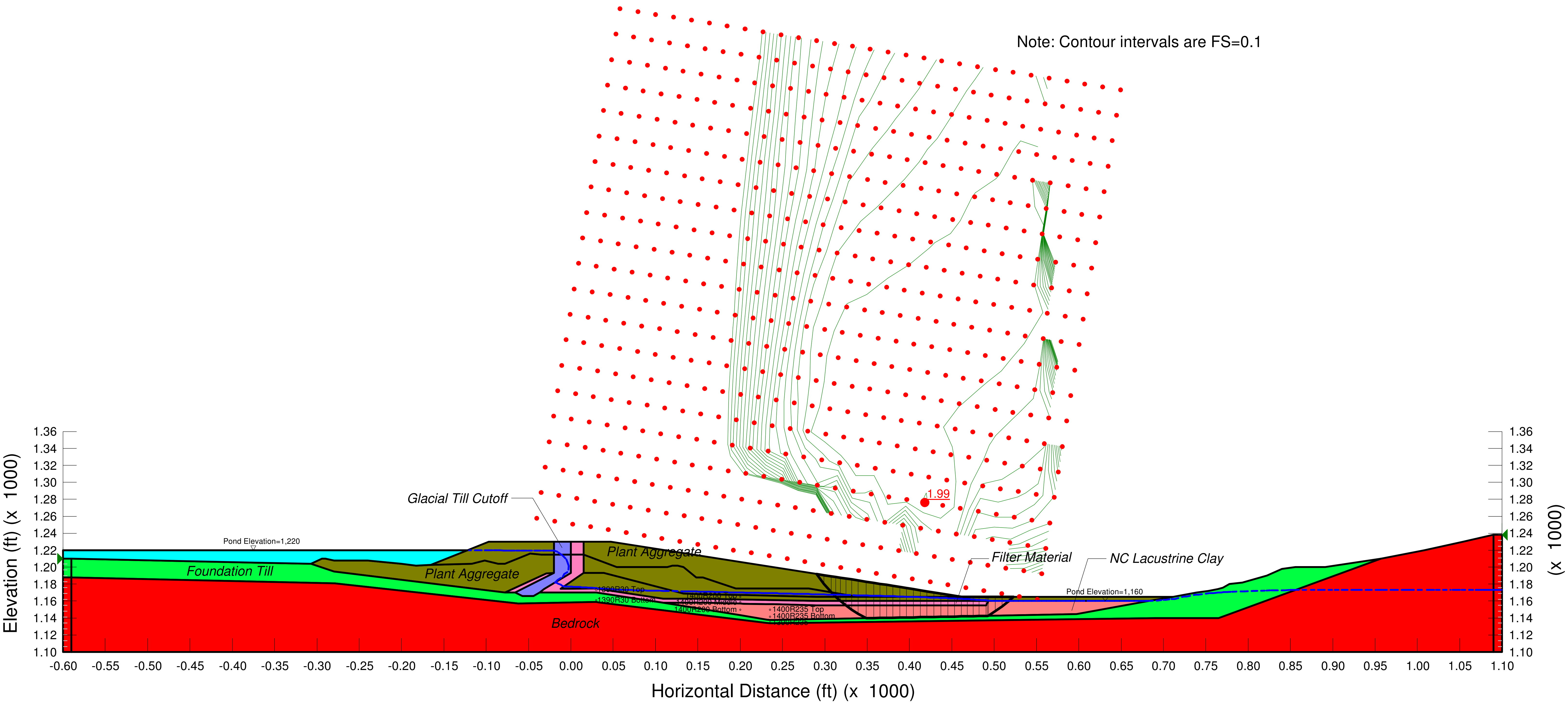
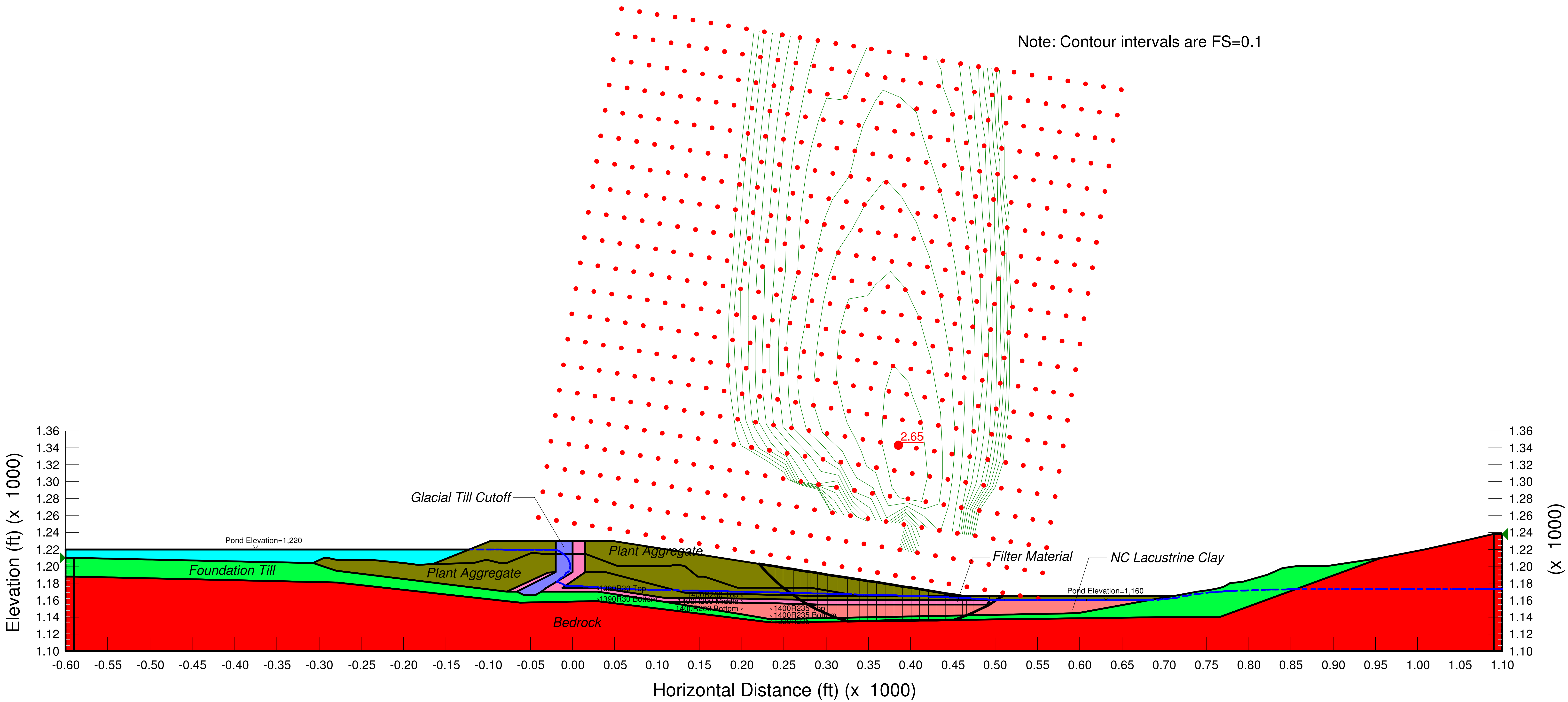
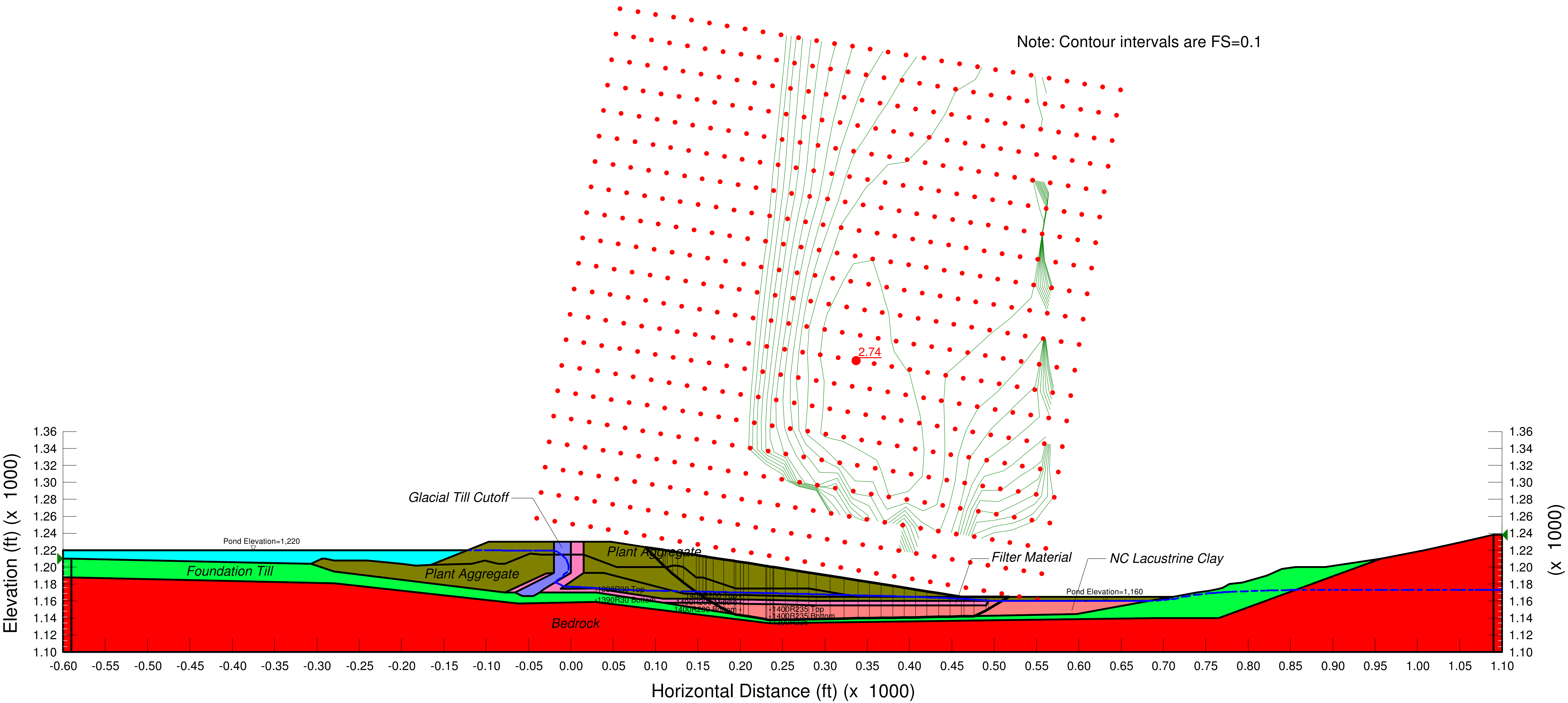
Last Saved Date: 8/21/2008
Factor of Safety: 1.99



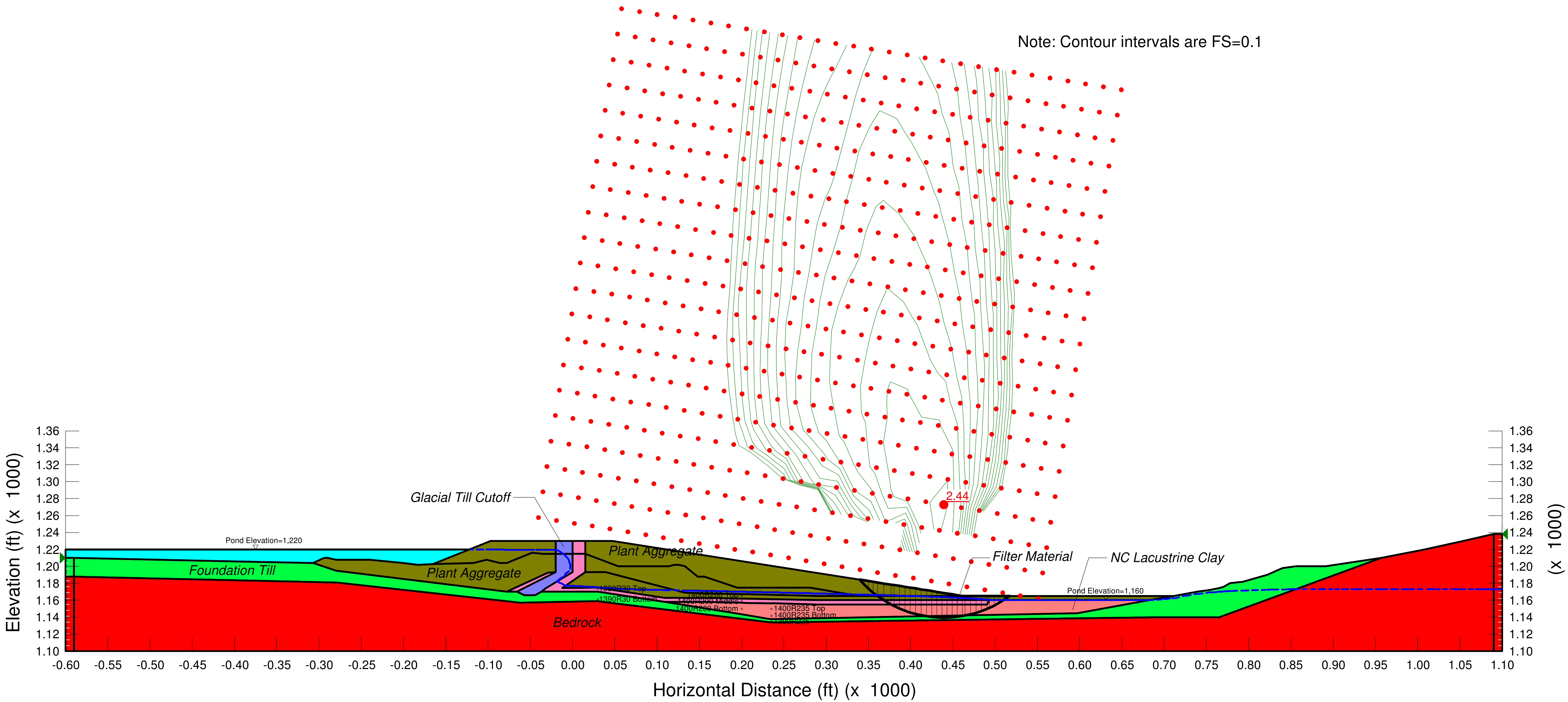
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Toe, Low Pond
File Name: D5_S1400_E1230_ESSA_LC2_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.65



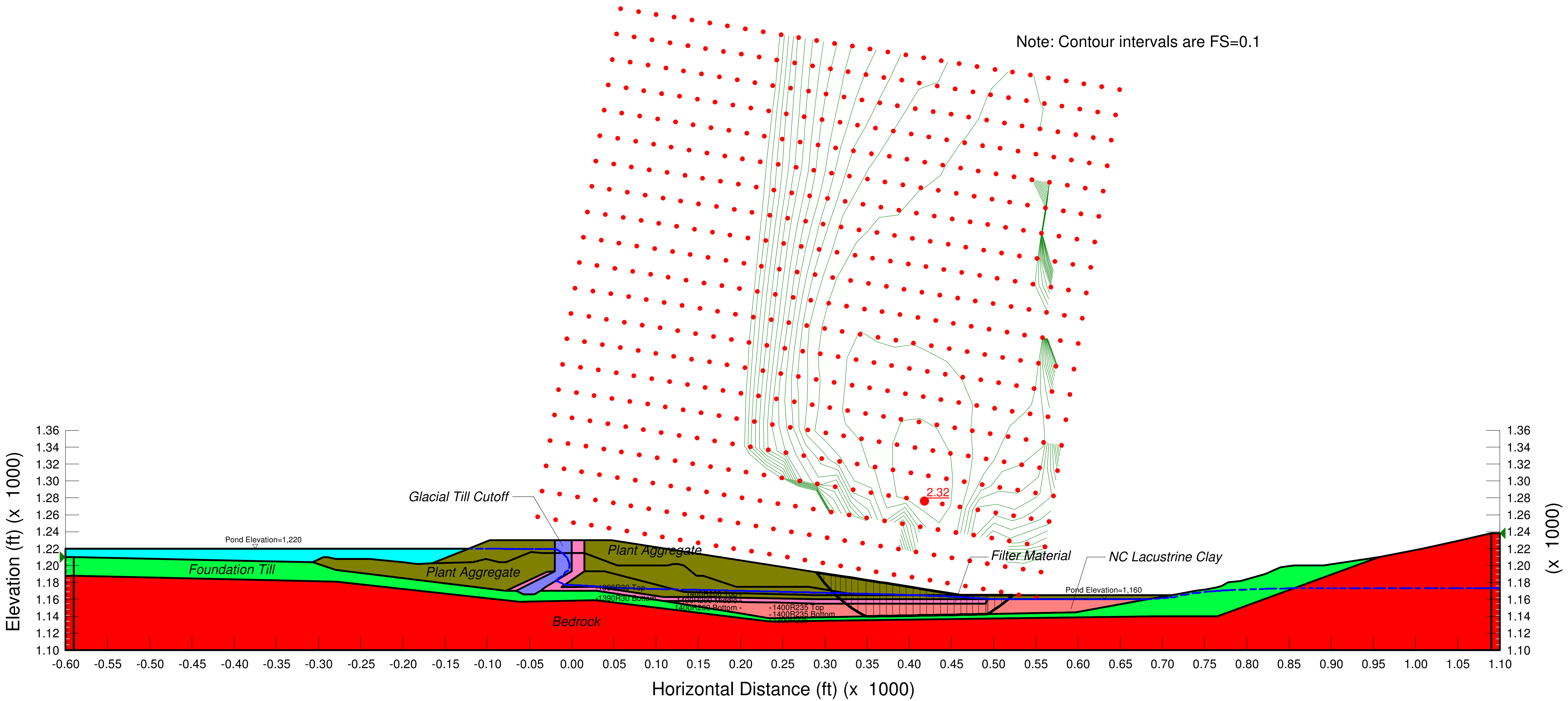
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Block, Low Pond
File Name: D5_S1400_E1230_ESSA_LC2_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.74



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Toe, Low Pond
File Name: D5_S1400_E1230_ESSA_LC3_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.44



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Block, Low Pond
File Name: D5_S1400_E1230_ESSA_LC3_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.32



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Toe, Low Pond
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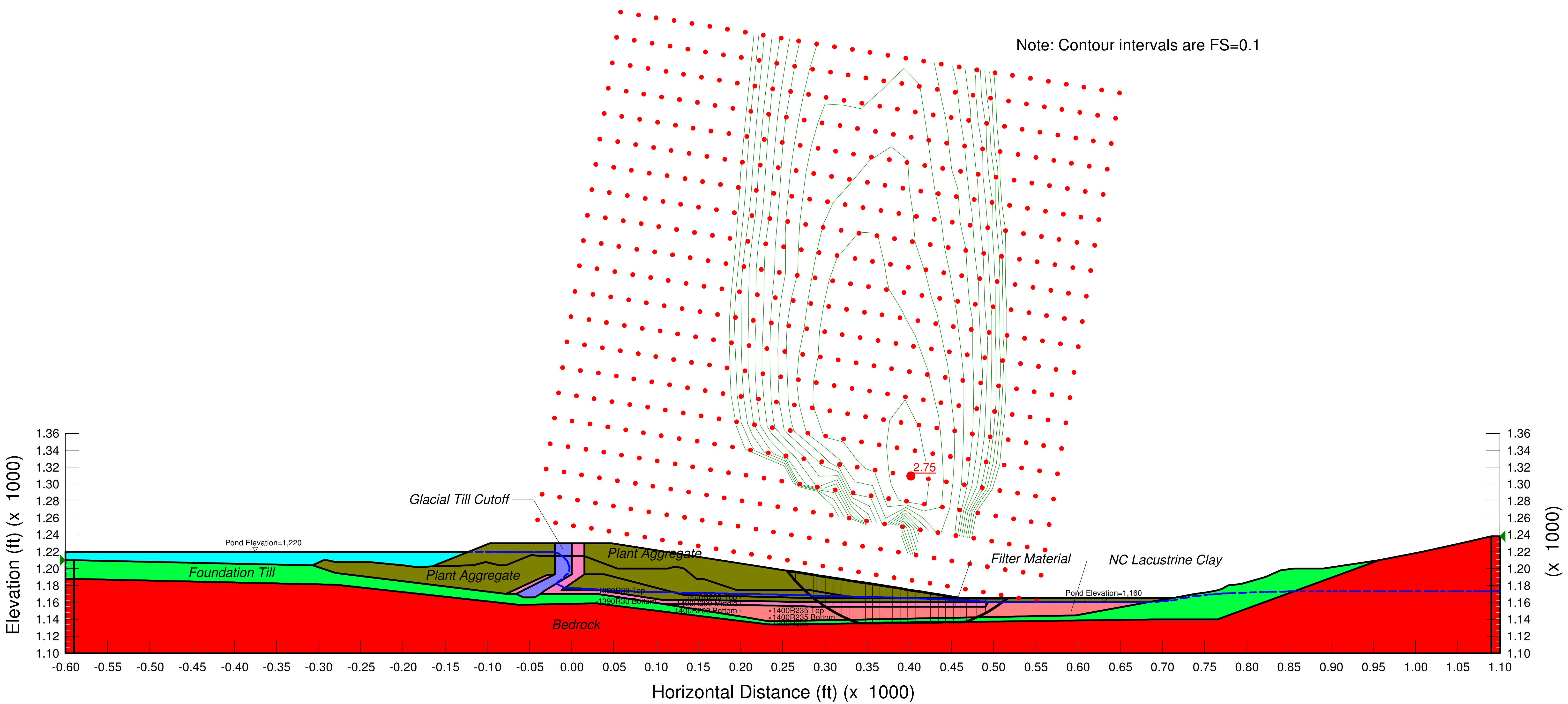
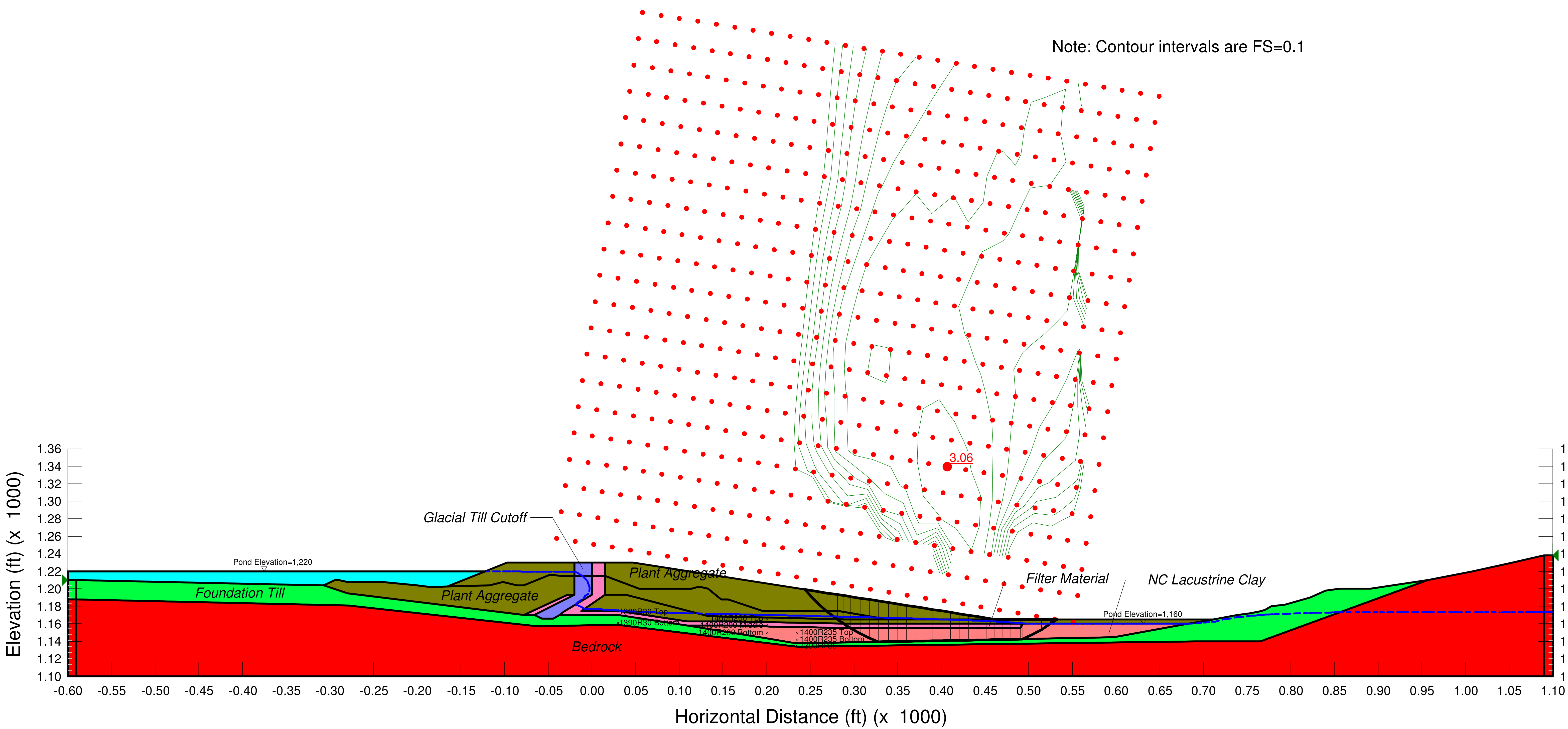
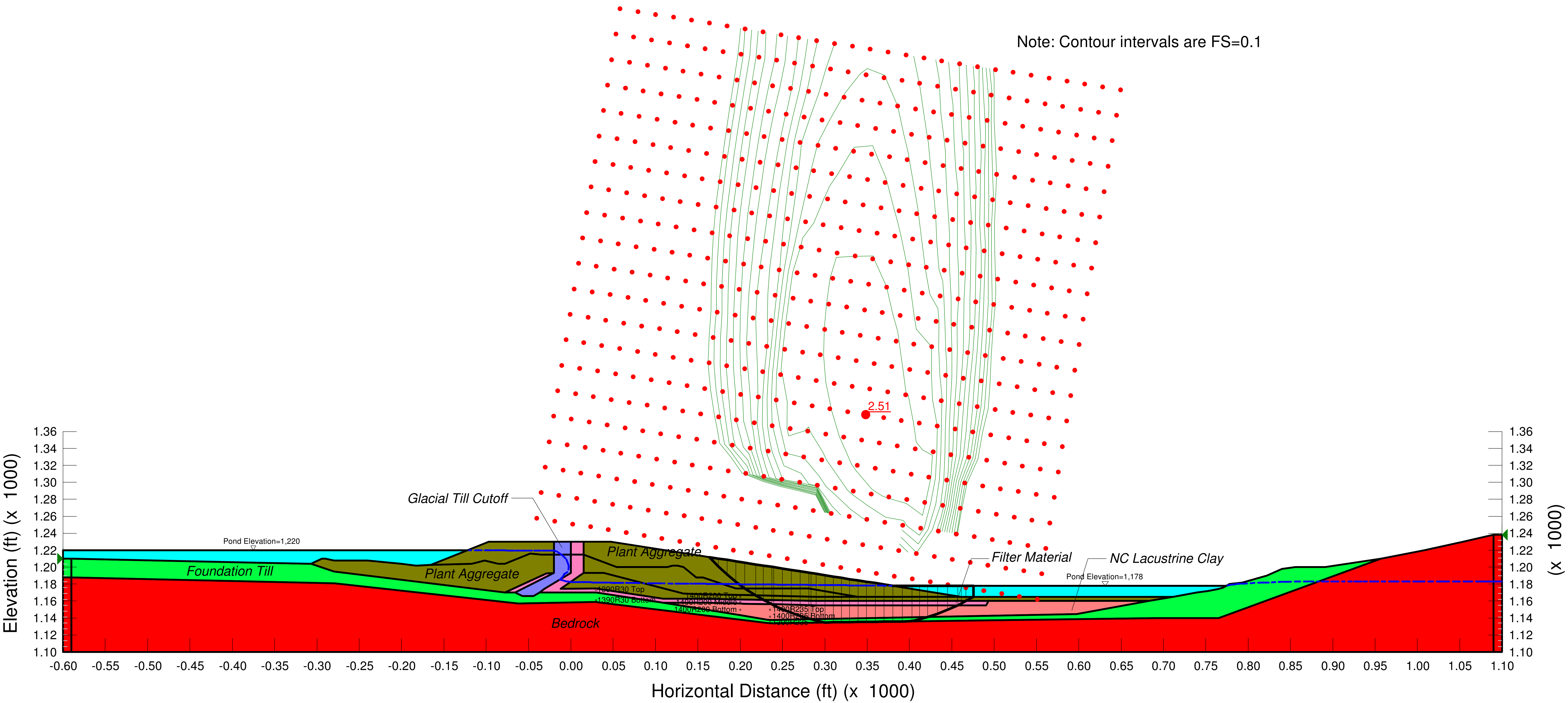
Last Saved Date: 8/21/2008
Factor of Safety: 2.75



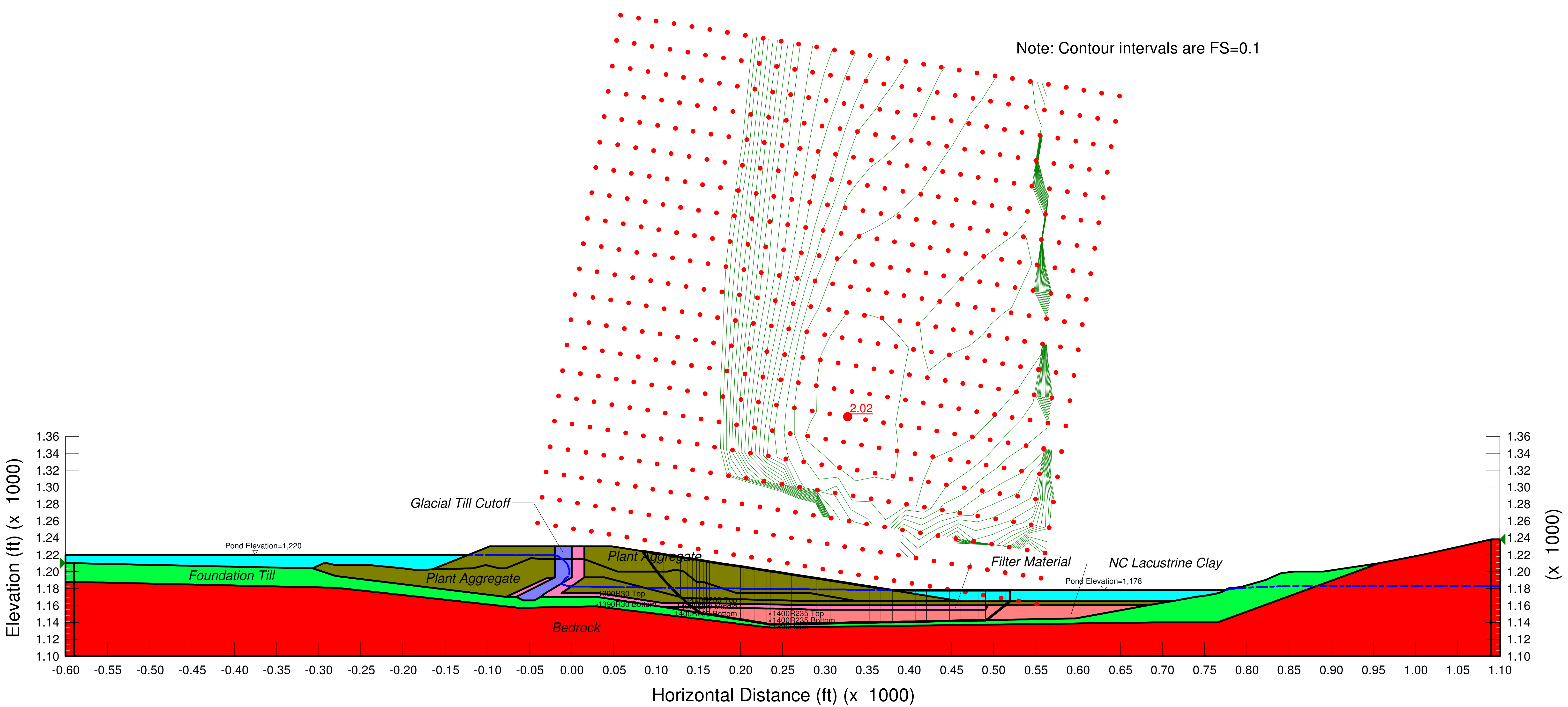
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Block, Low Pond
File Name: D5_S1400_E1230_ESSA_LC4_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 3.06



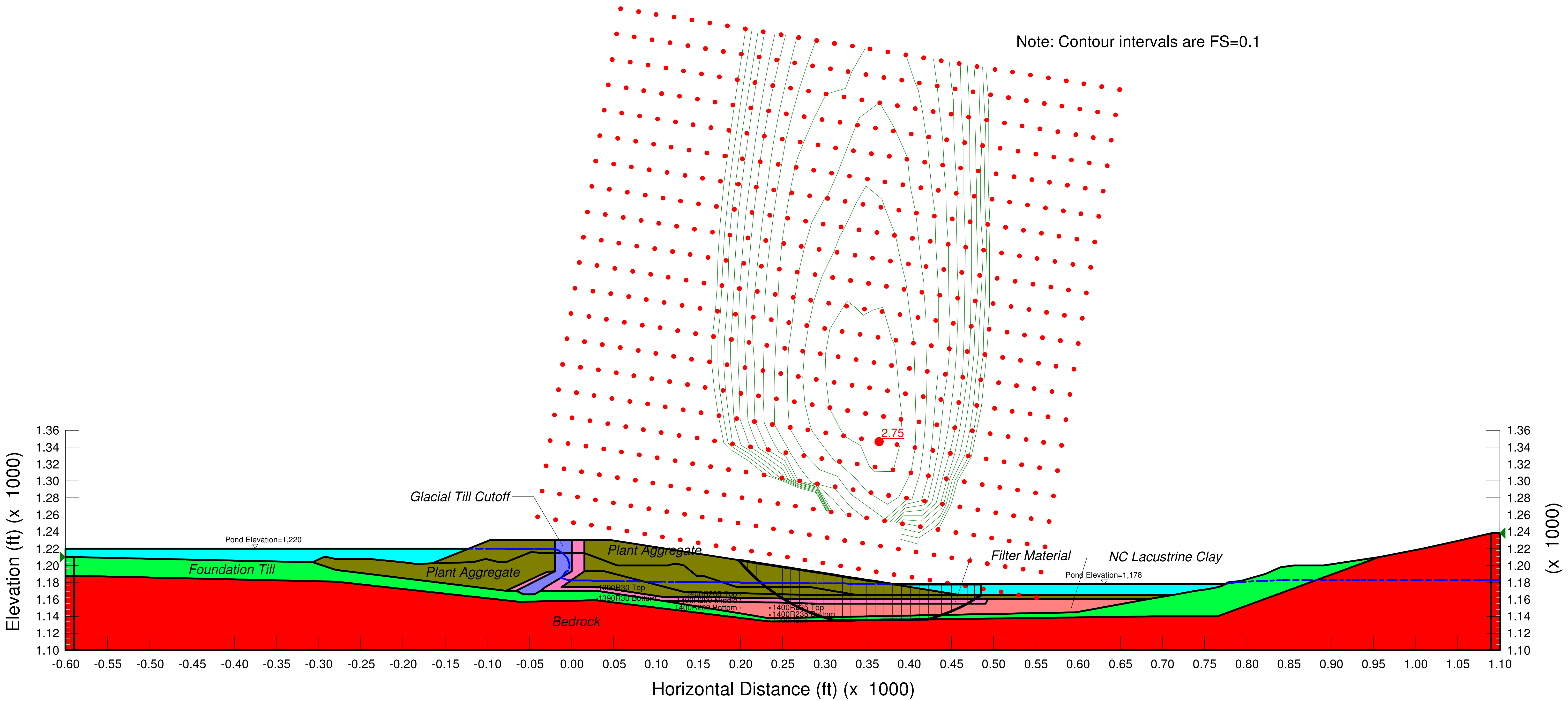
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Toe, High Pond
File Name: D5_S1400_E1230_ESSA_LC1_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.51



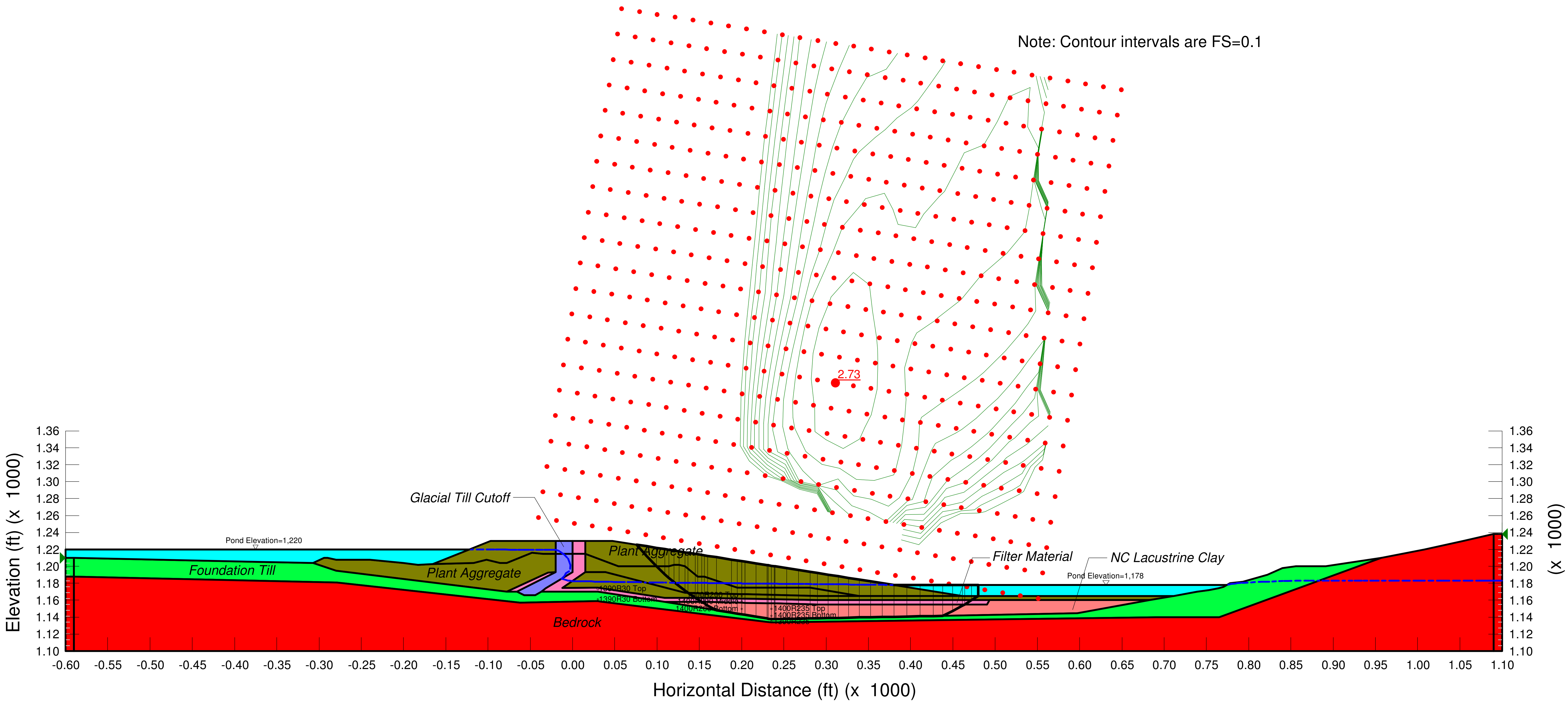
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Low, FM Block, High Pond
File Name: D5_S1400_E1230_ESSA_LC1_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.02



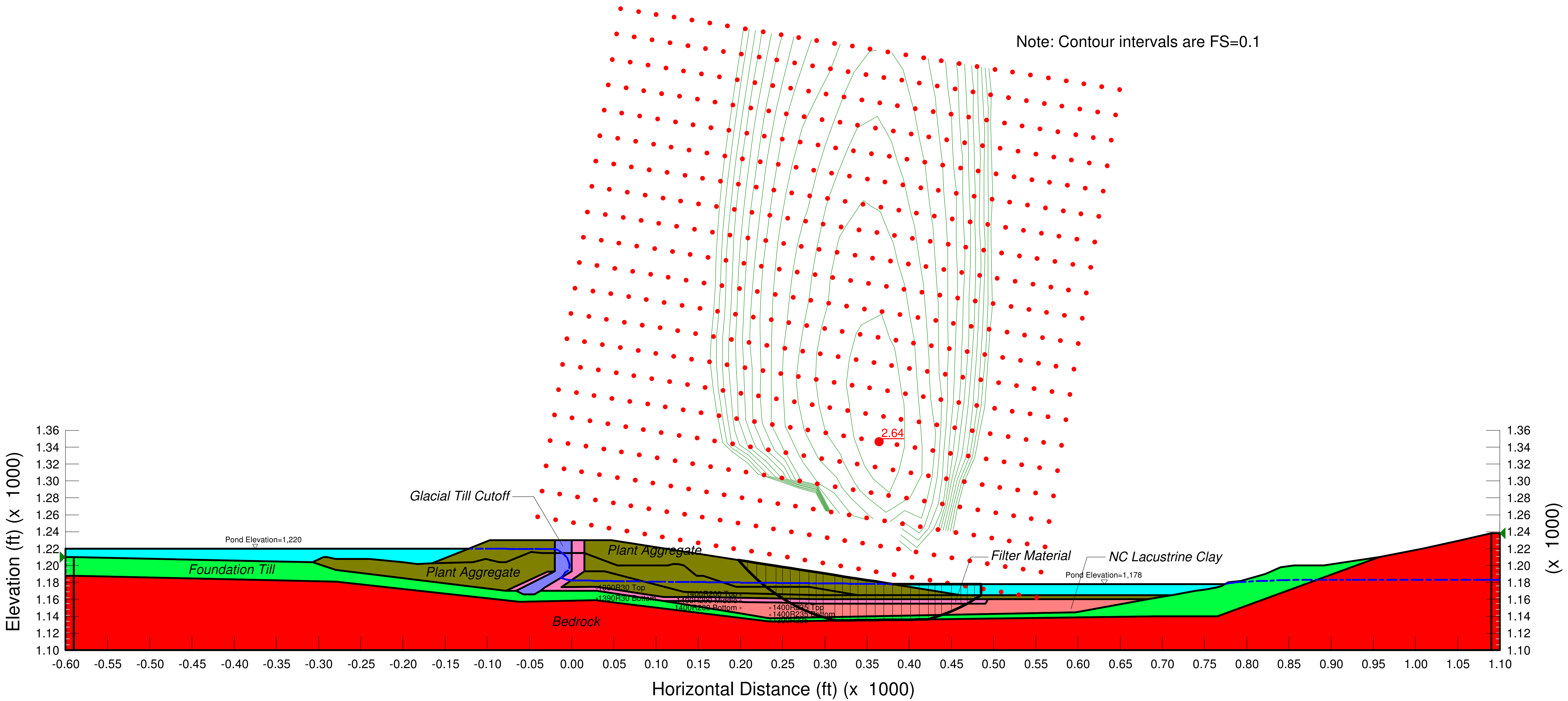
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Toe, High Pond
File Name: D5_S1400_E1230_ESSA_LC2_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.75



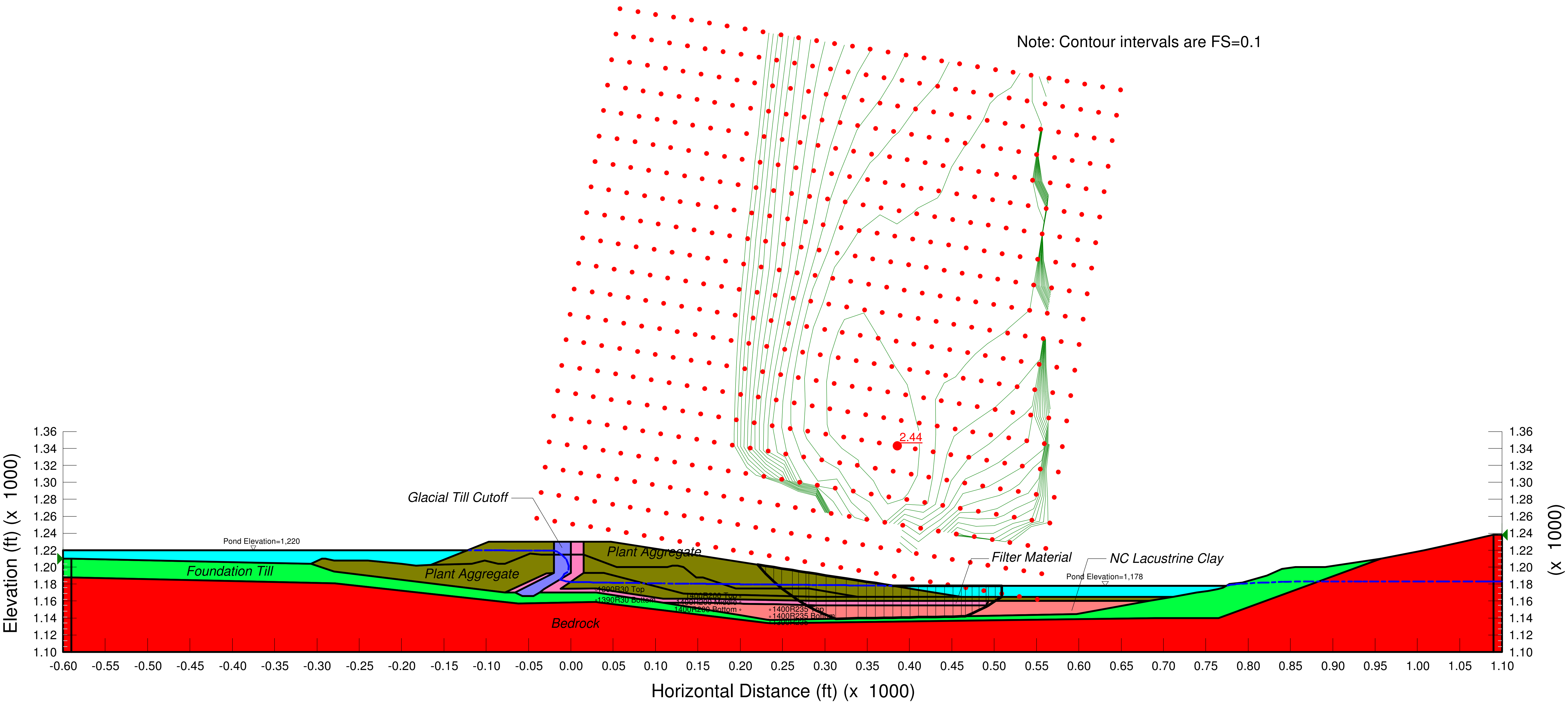
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC DSS Average, FM Block, High Pond
File Name: D5_S1400_E1230_ESSA_LC2_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.73



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Toe, High Pond
File Name: D5_S1400_E1230_ESSA_LC3_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.64



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Low, FM Block, High Pond
File Name: D5_S1400_E1230_ESSA_LC3_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.44



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Toe, High Pond
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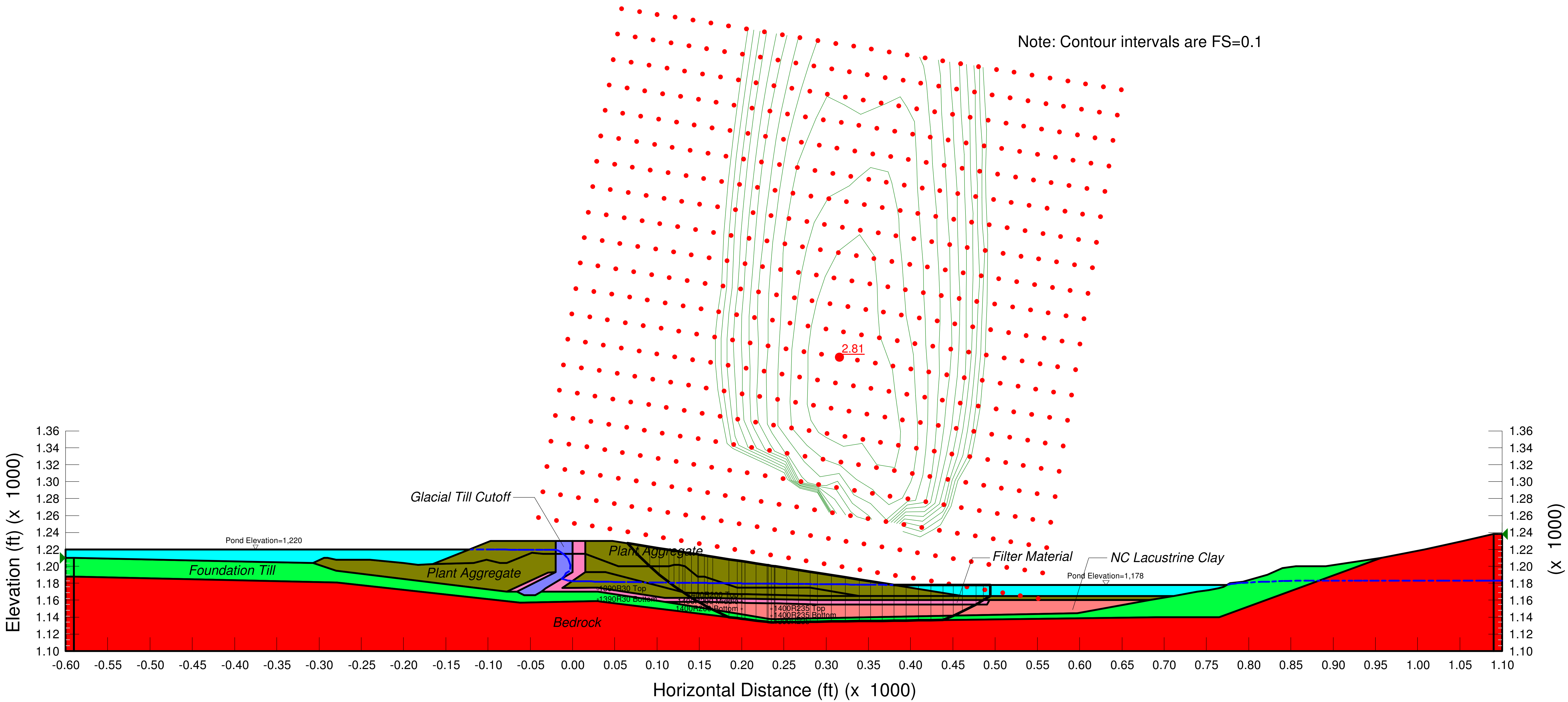
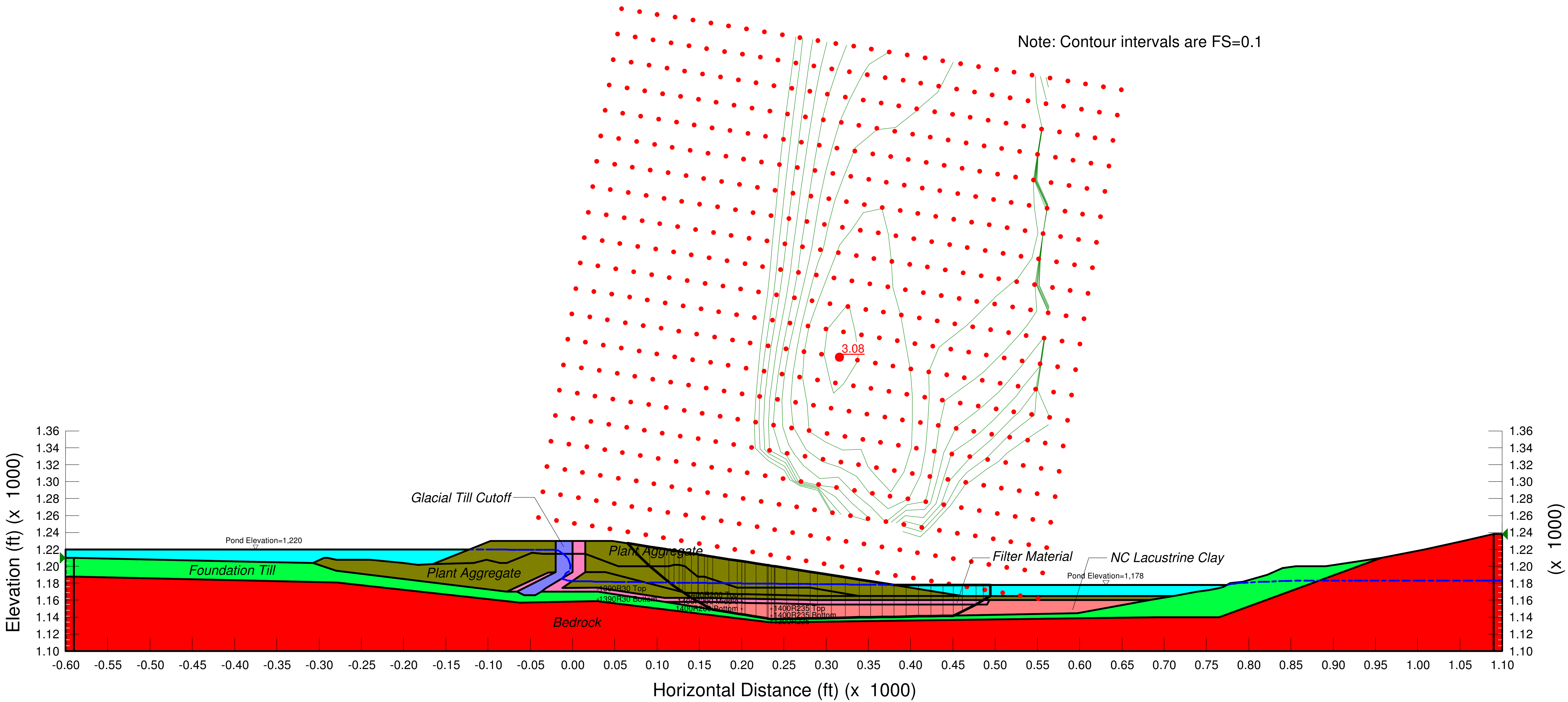
Factor of Safety: 2.81

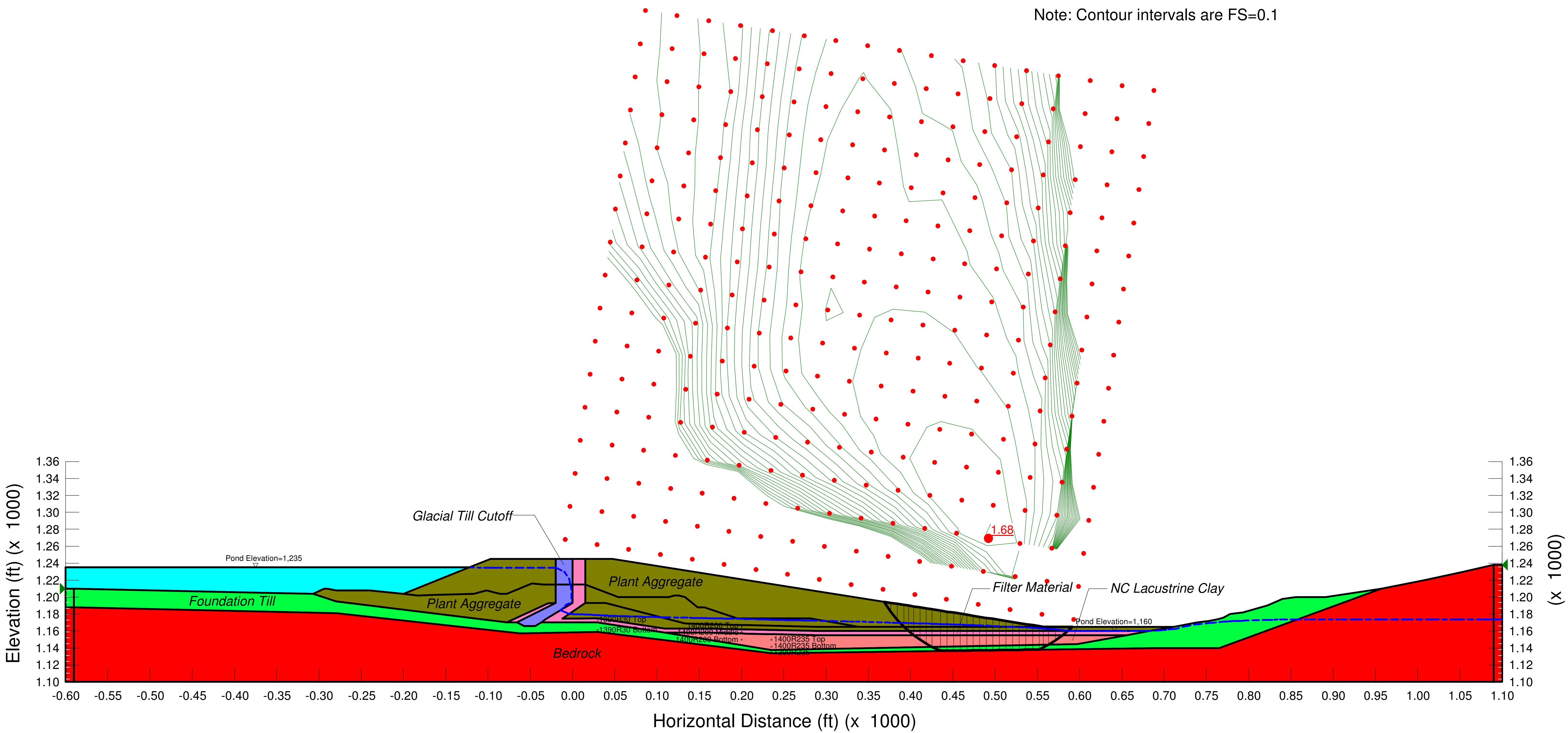


Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1230), ESSA, LC TXC Average, FM Block, High Pond
File Name: D5_S1400_E1230_ESSA_LC4_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 3.08

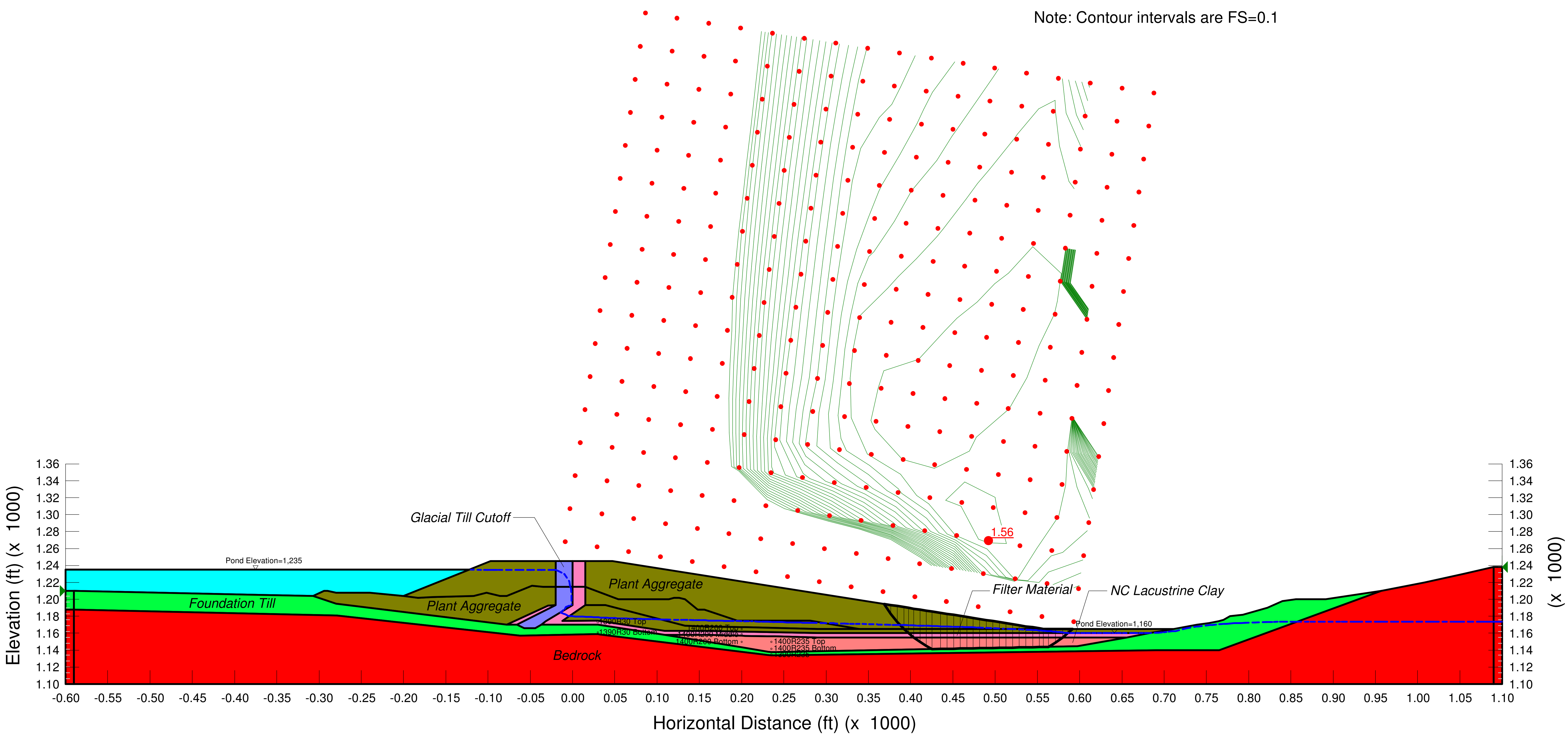


Proposed Geometry El. 1,245 feet

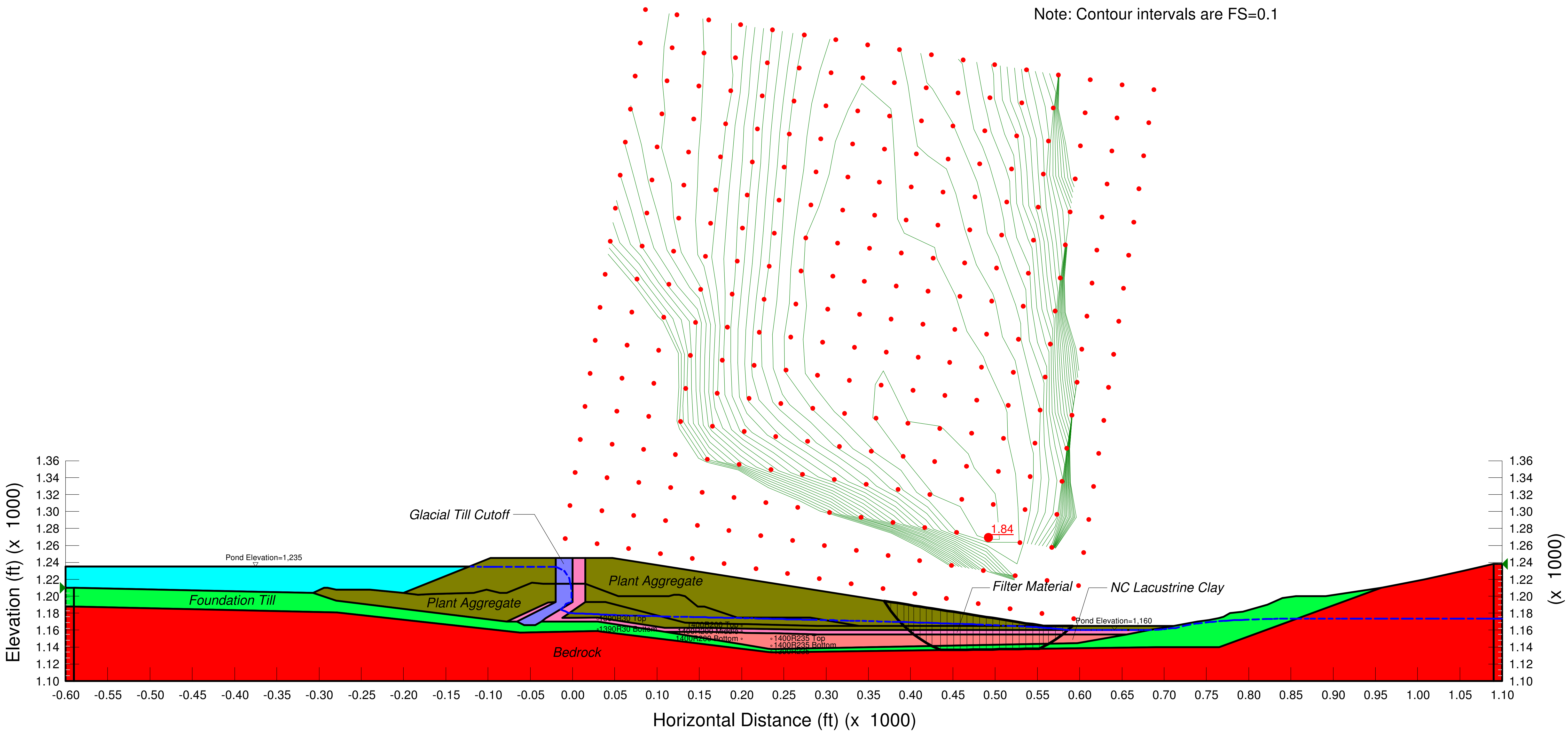
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FM Toe, Low Pond
File Name: D5_S1400_E1245_USSA_LC5_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.68



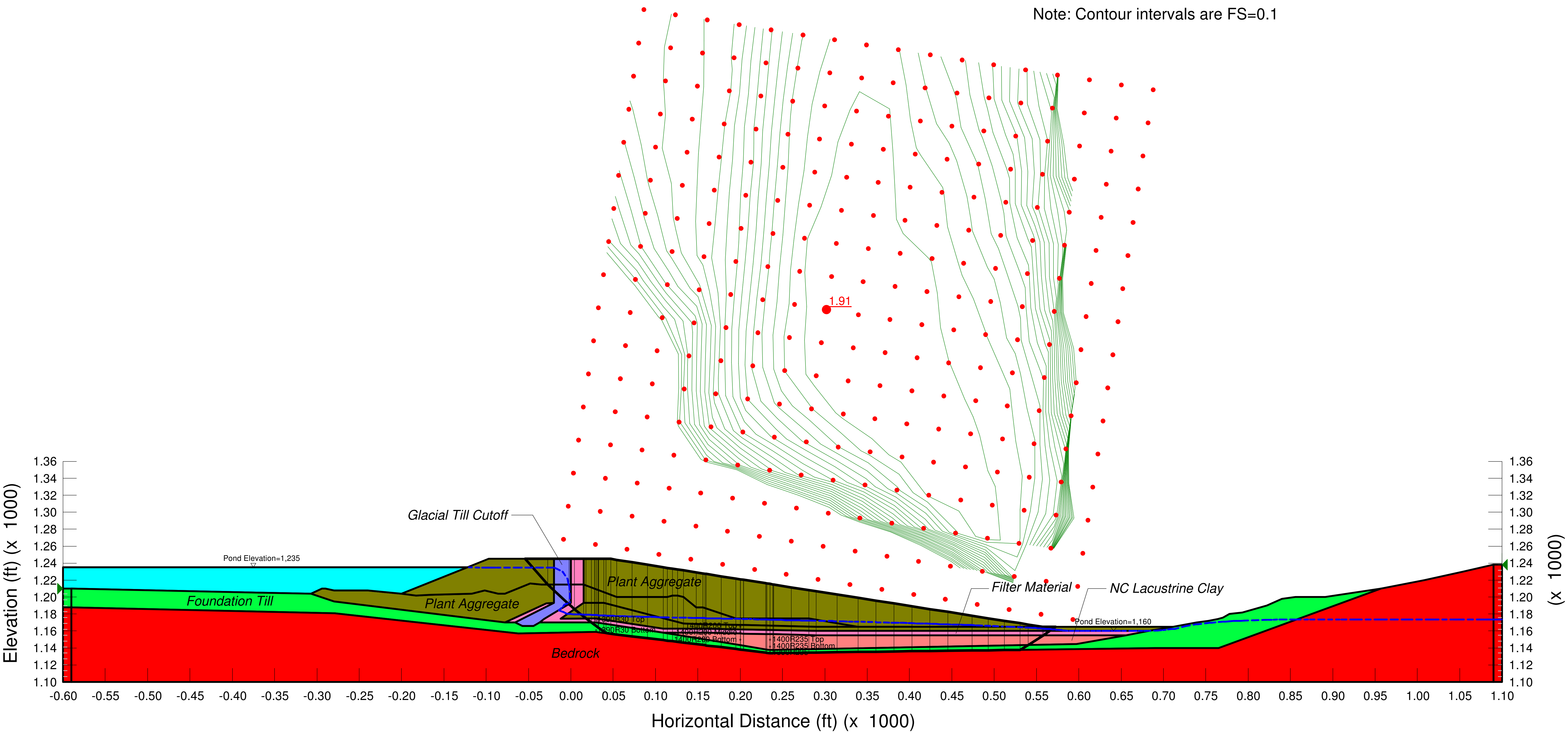
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FM Block, Low Pond
File Name: D5_S1400_E1245_USSA_LC5_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.56



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FM Toe, Low Pond
File Name: D5_S1400_E1245_USSA_LC6_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.84



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FM Toe, Low Pond
File Name: D5_S1400_E1245_USSA_LC8_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.91



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FM Block, Low Pond
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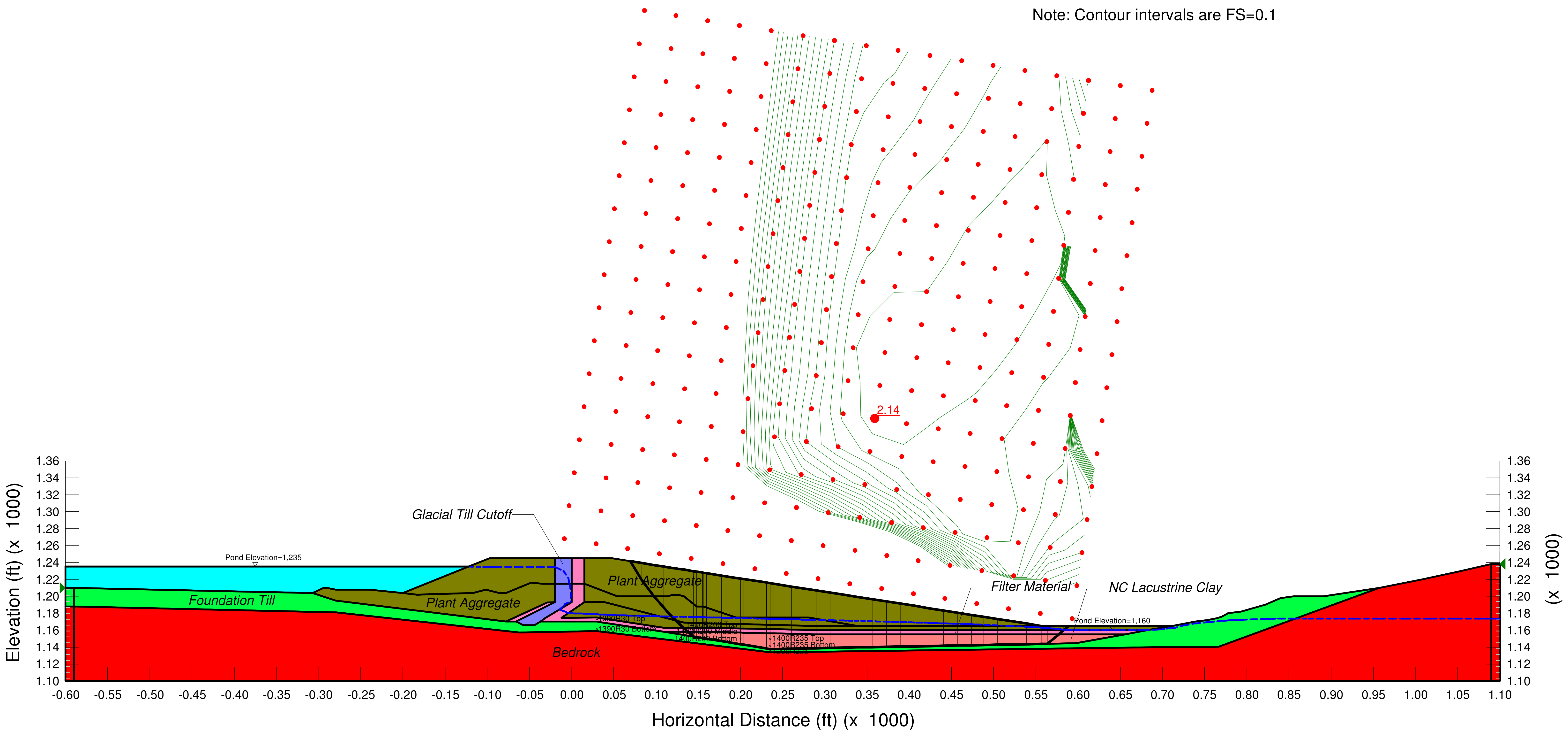
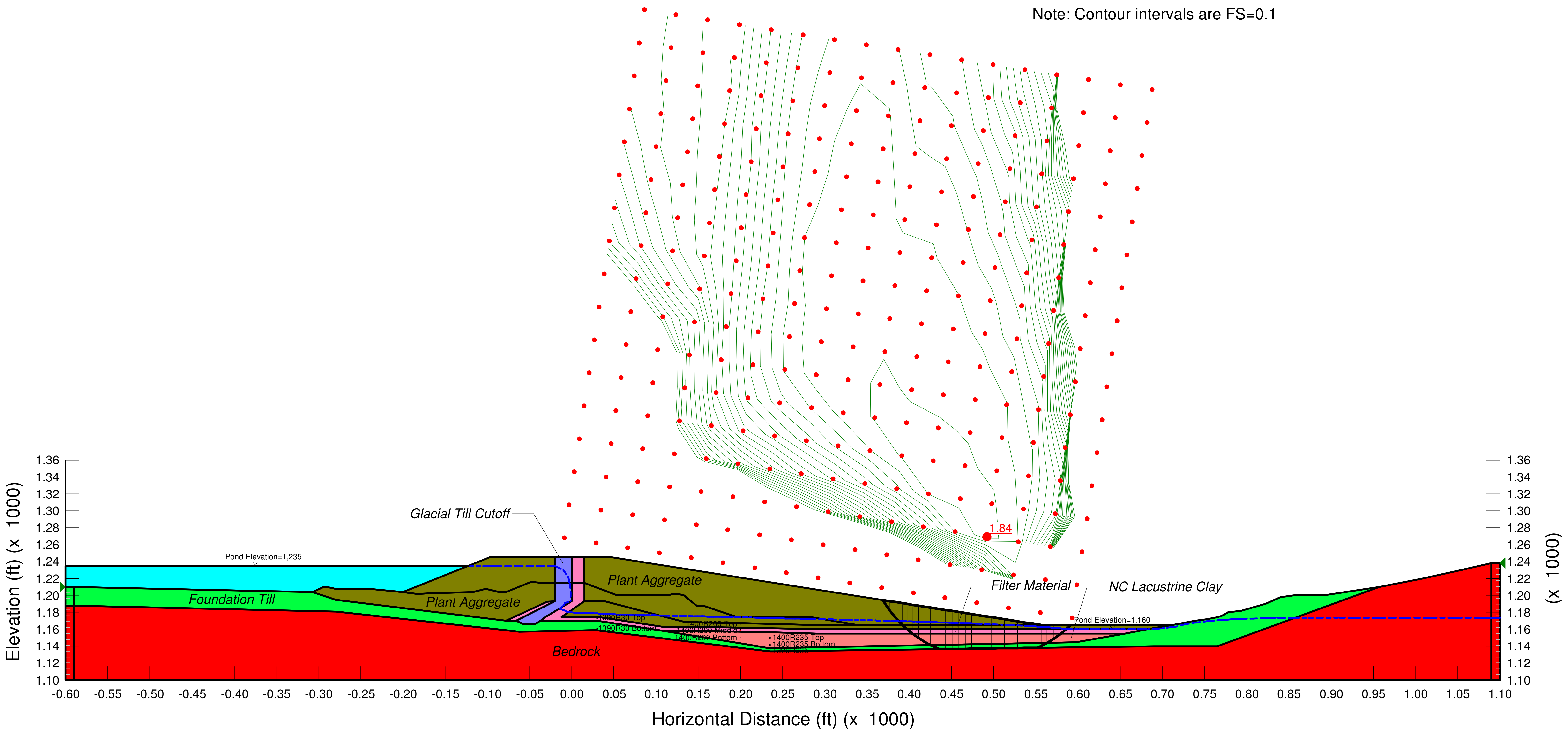
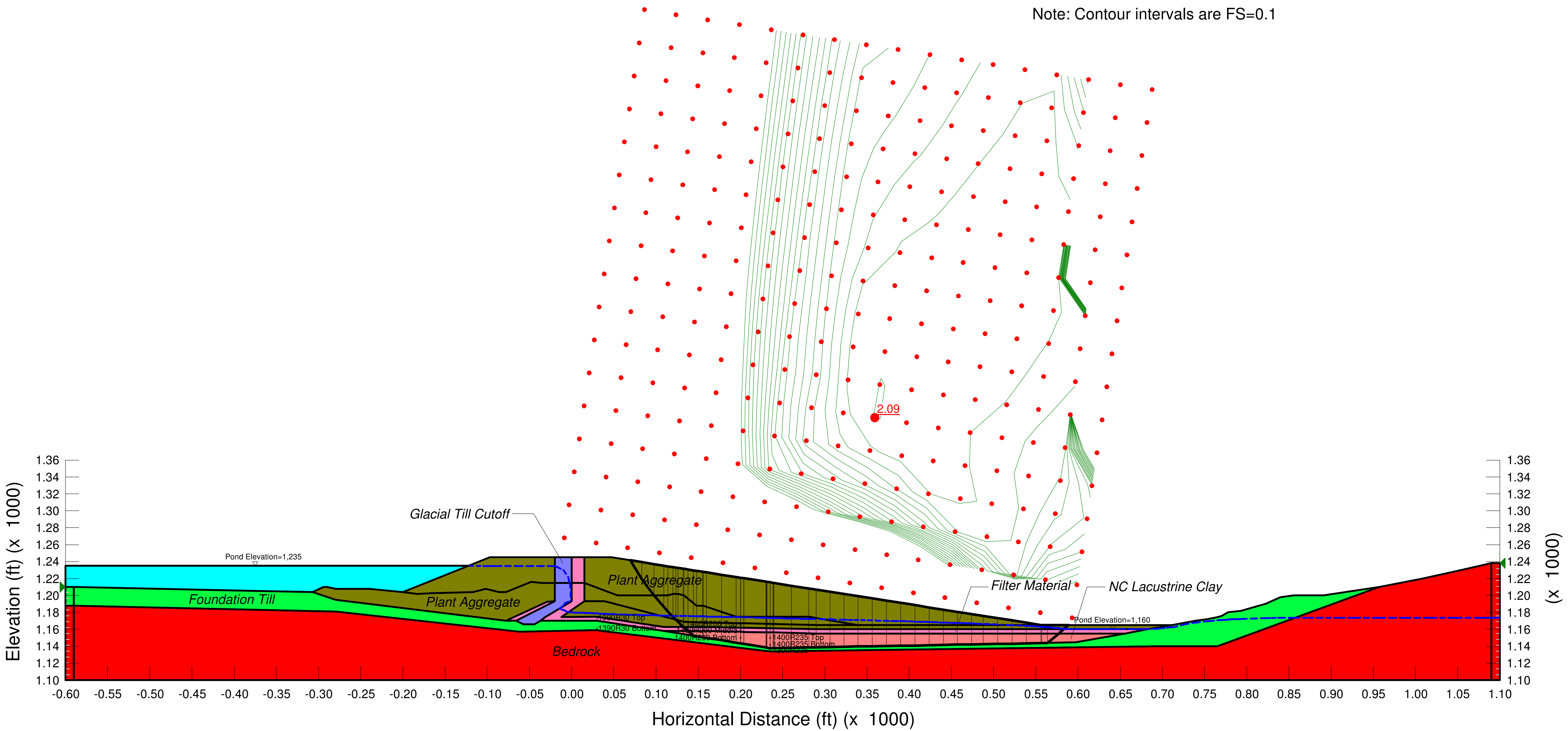
Last Saved Date: 8/21/2008
Factor of Safety: 2.14



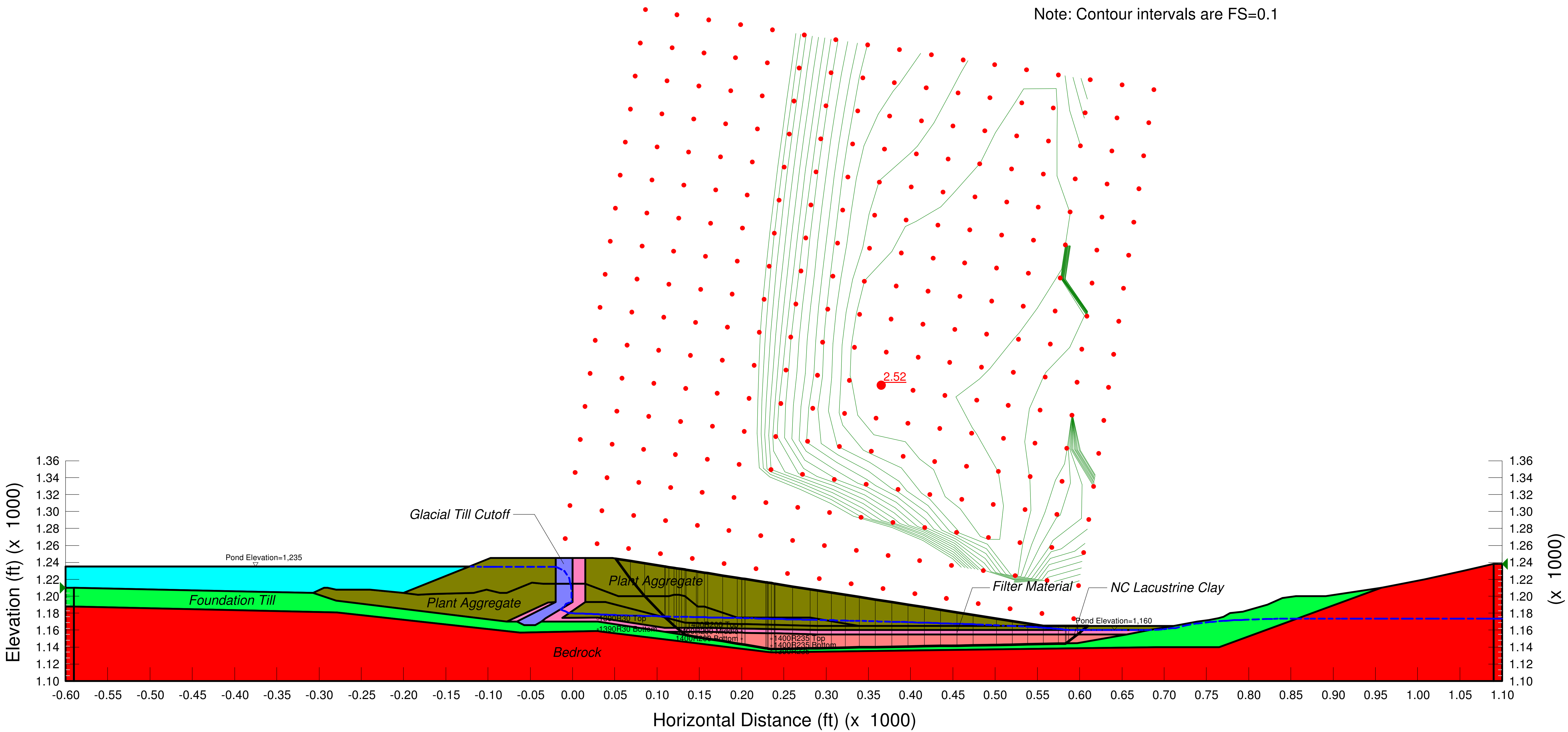
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FM Toe, Low Pond
File Name: D5_S1400_E1245_USSA_LC7_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.84



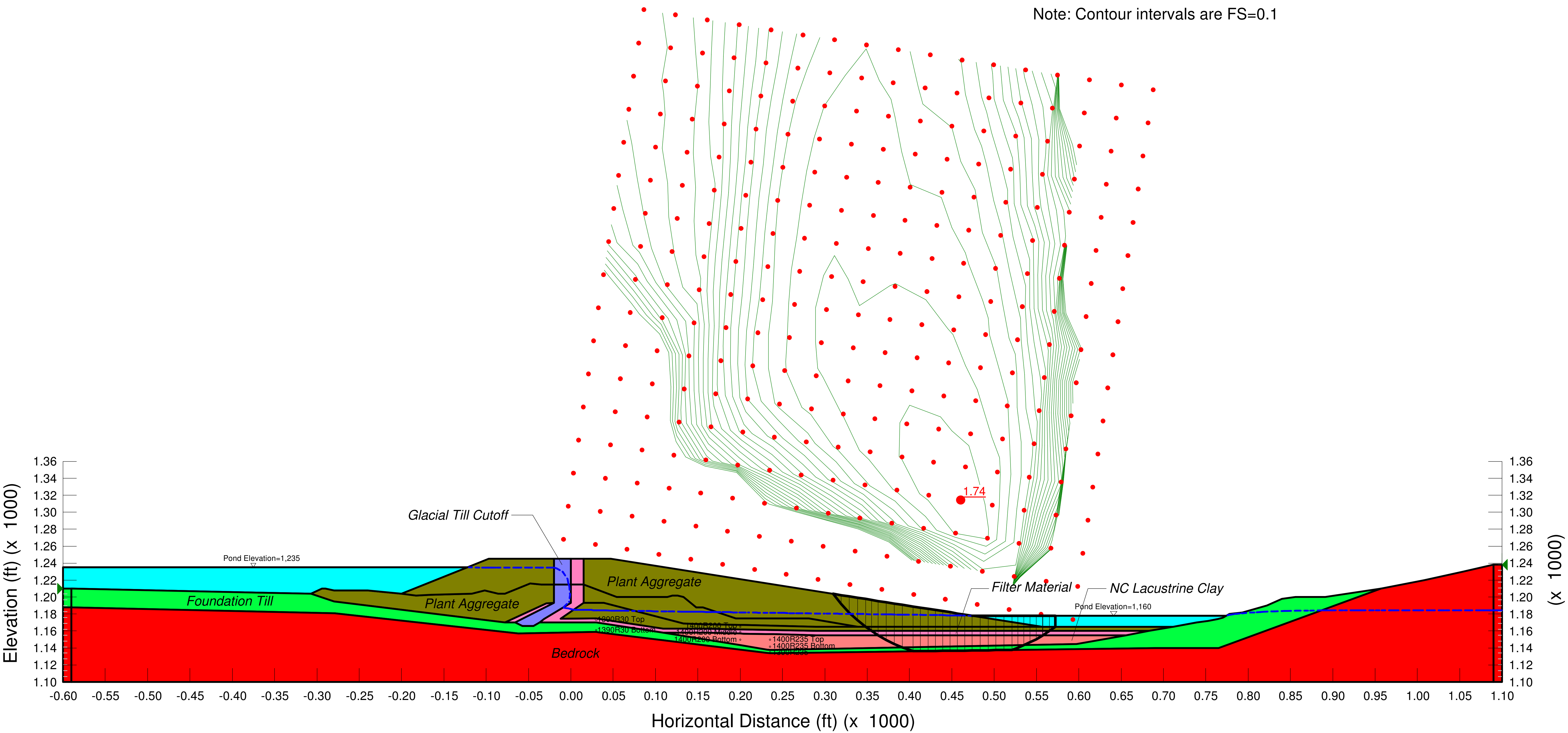
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FM Block, Low Pond
File Name: D5_S1400_E1245_USSA_LC7_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.09



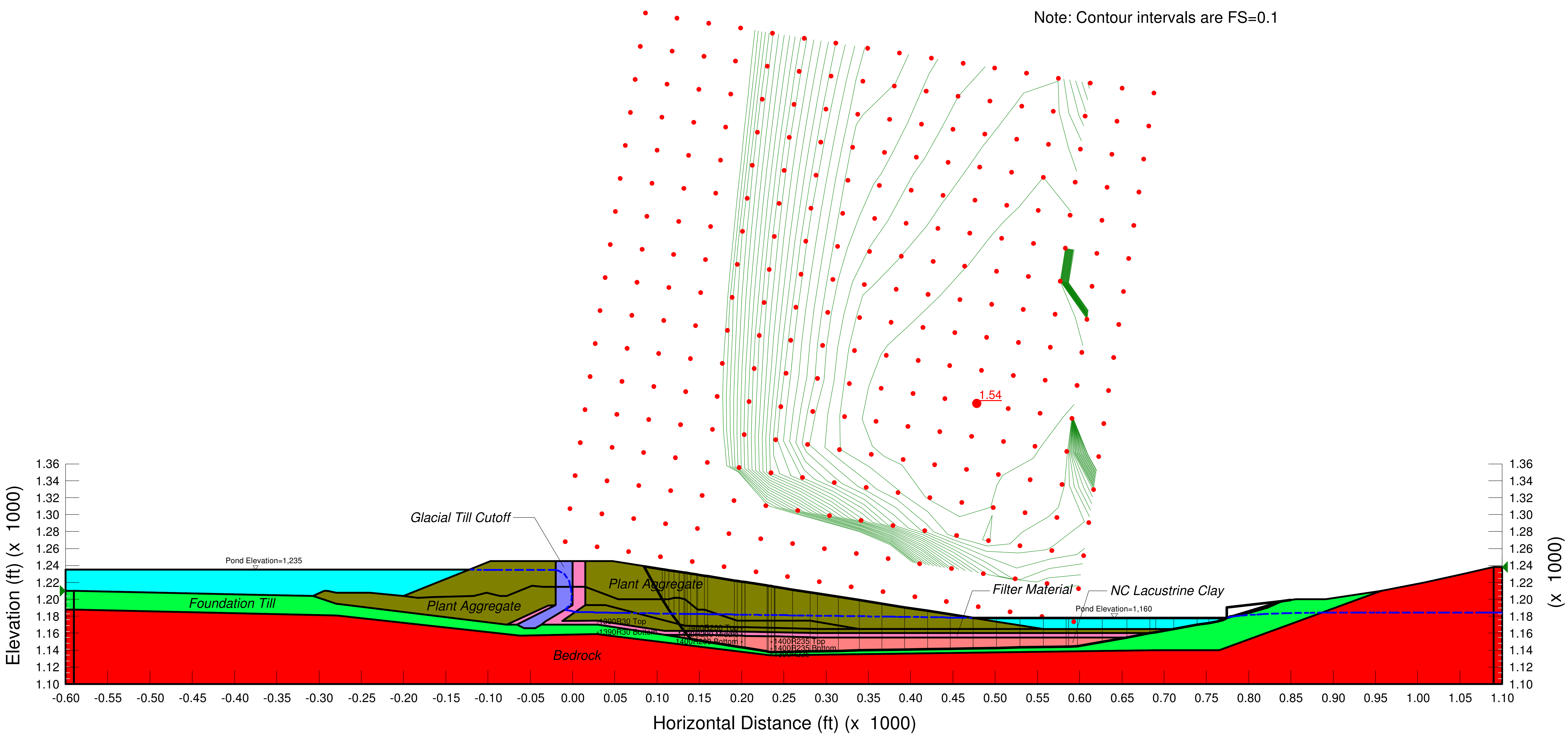
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FM Block, Low Pond
File Name: D5_S1400_E1245_USSA_LC8_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.52



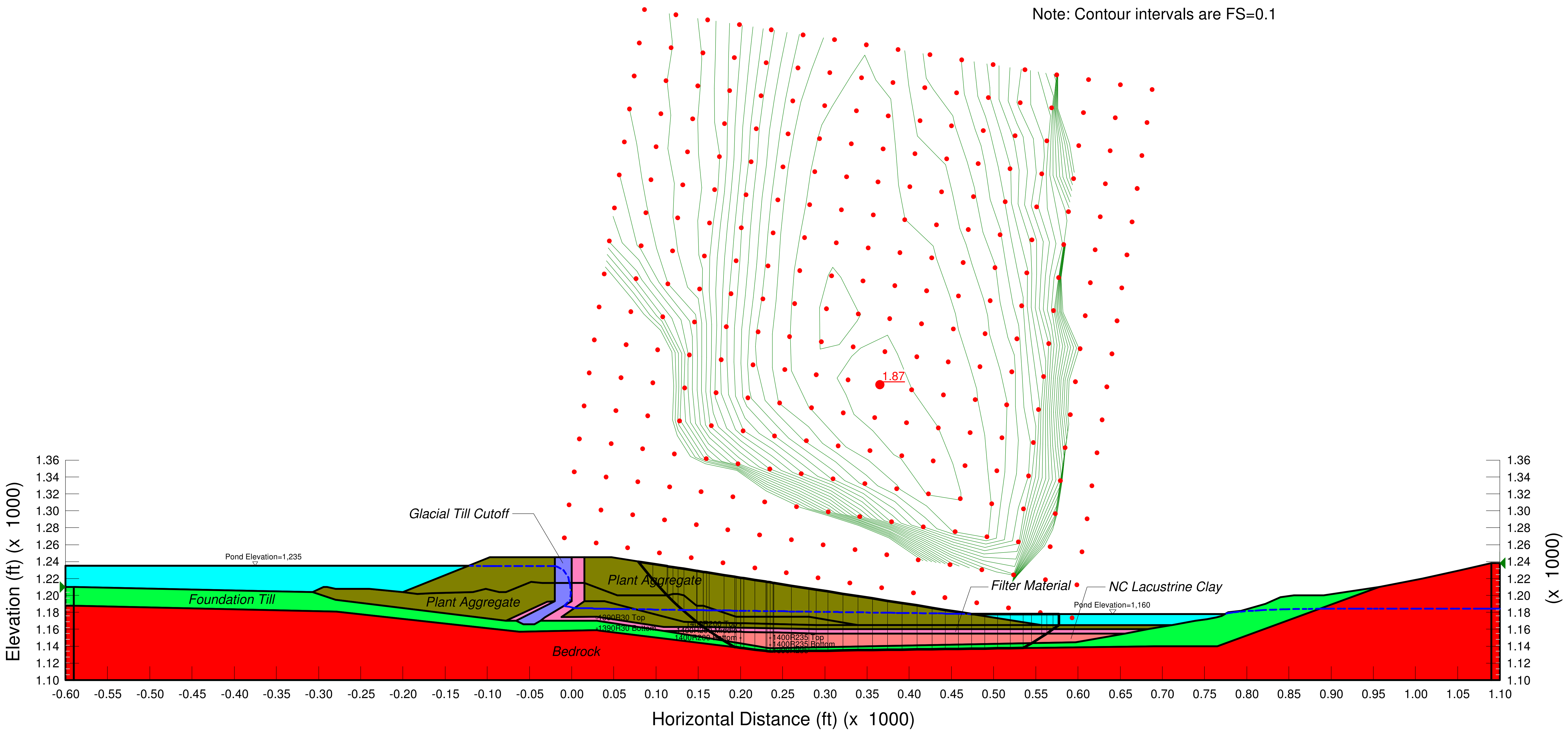
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FM Toe, High Pond
File Name: D5_S1400_E1245_USSA_LC5_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.74



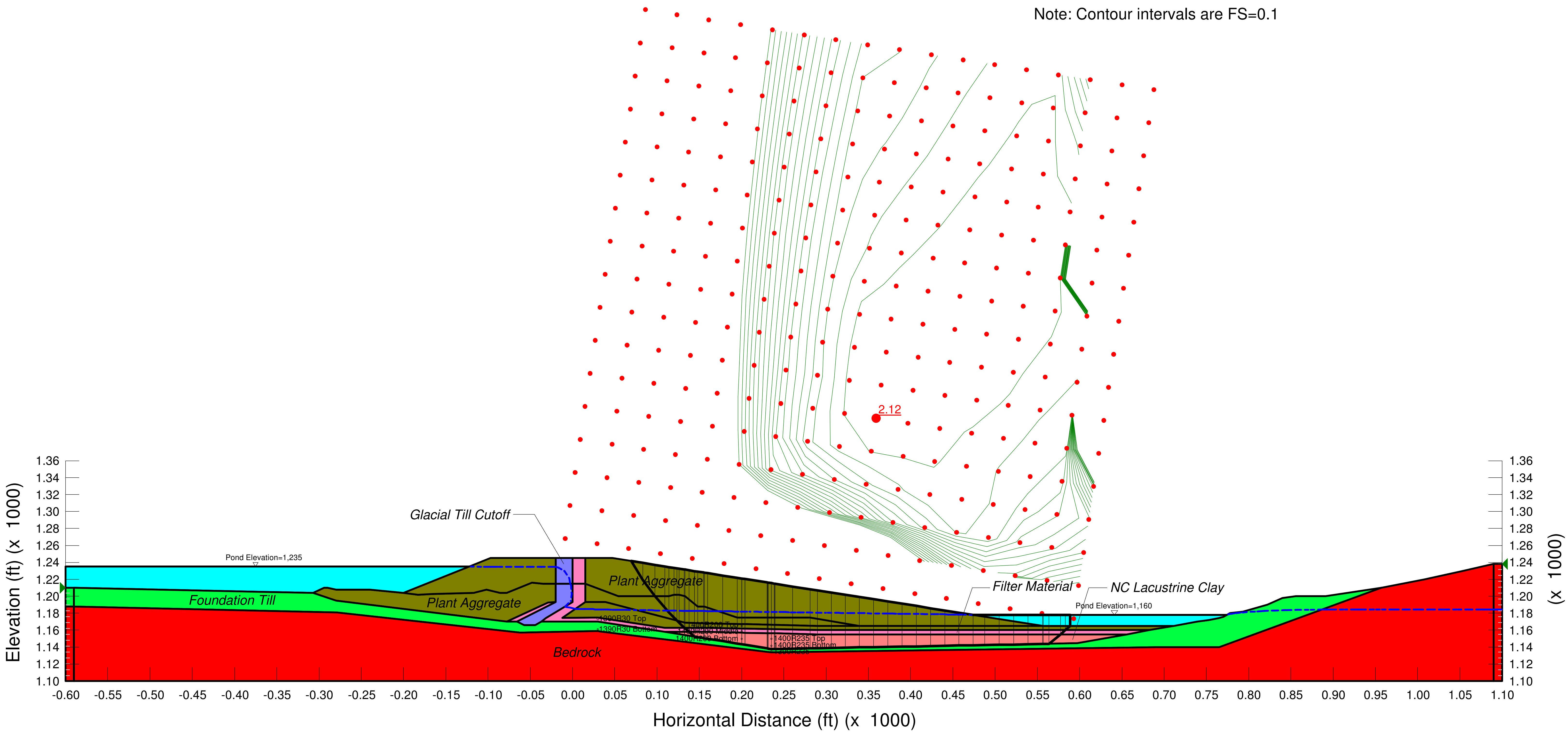
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Low, FM Block, High Pond
File Name: D5_S1400_E1245_USSA_LC5_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.54



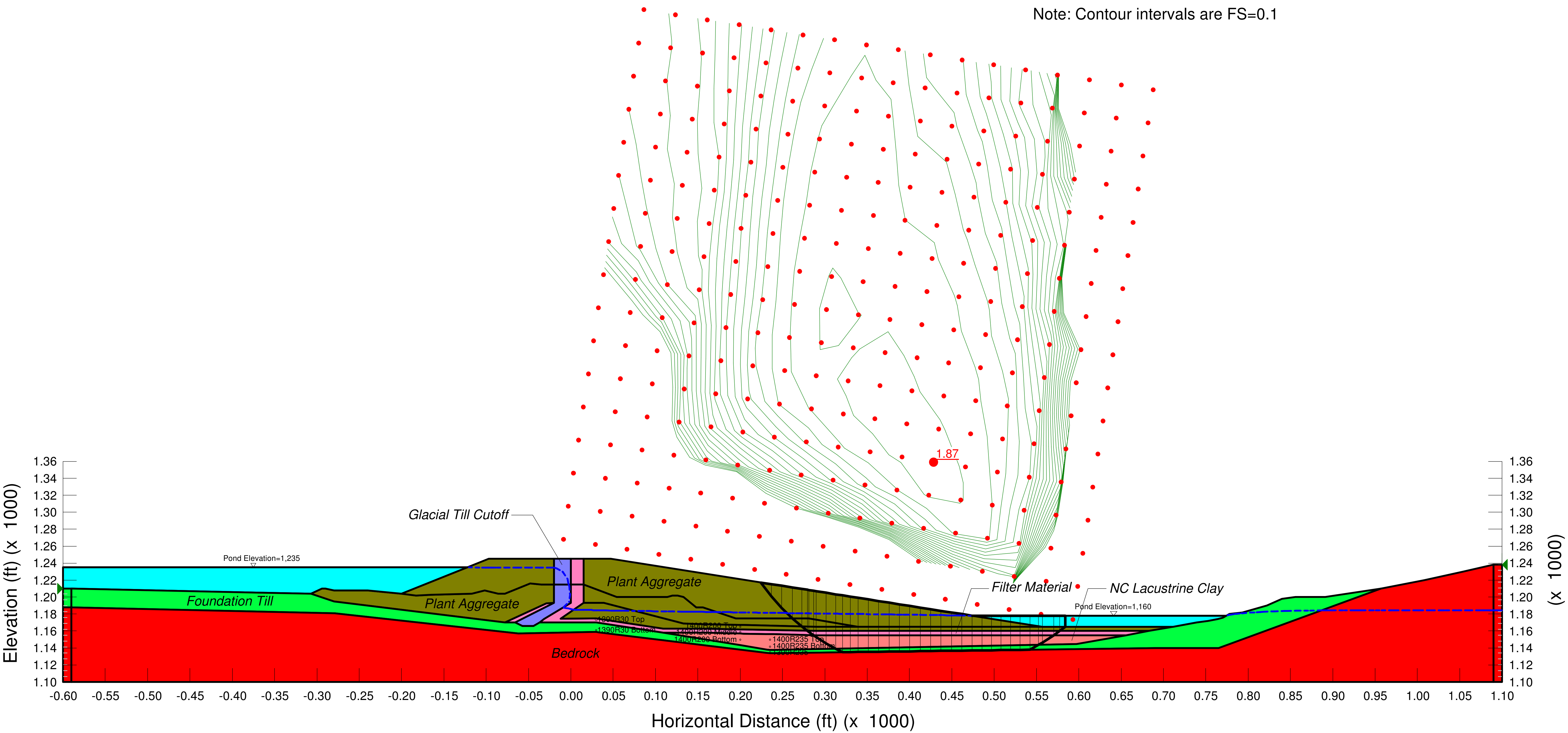
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FM Toe, High Pond
File Name: D5_S1400_E1245_USSA_LC6_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.87



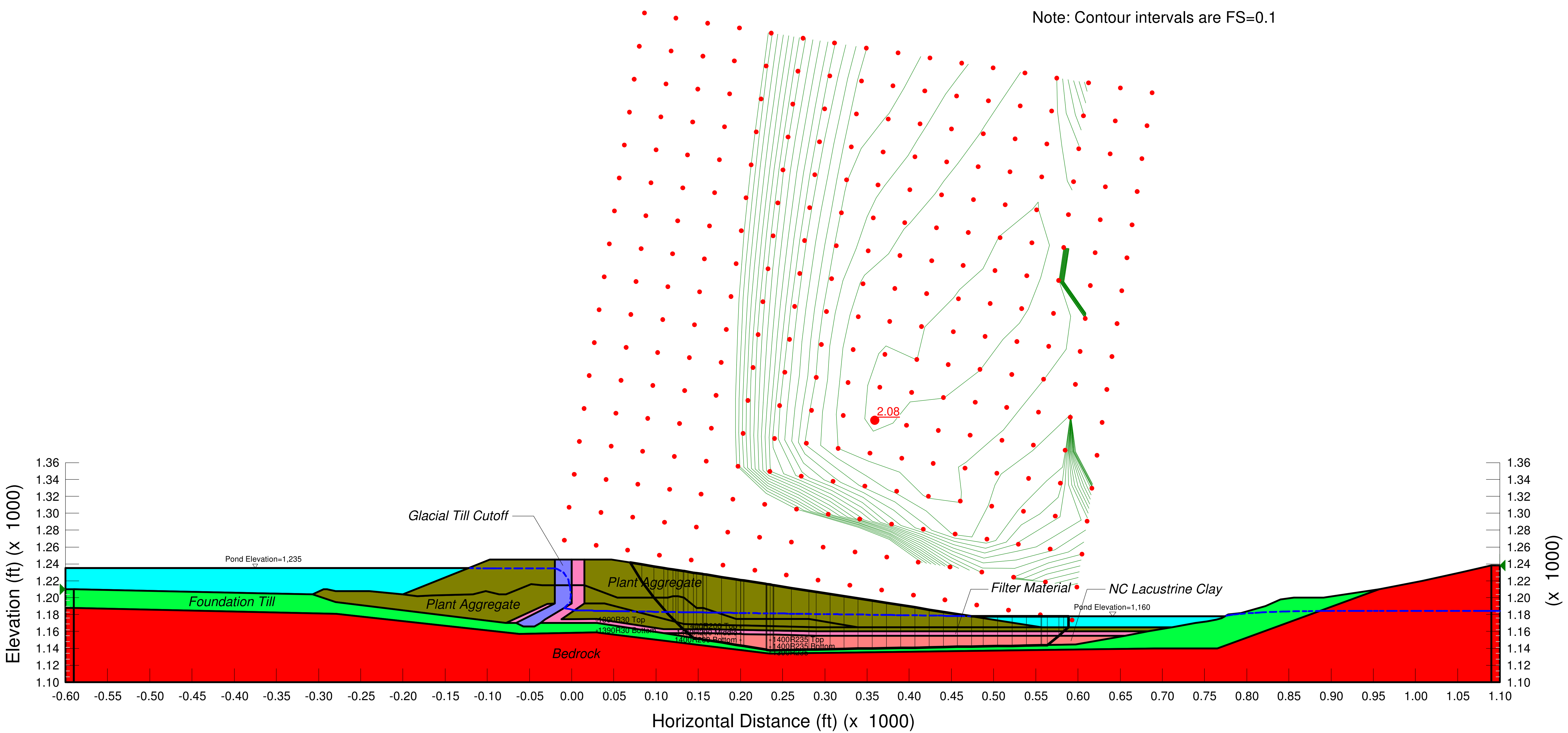
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC DSS Average, FM Block, High Pond
File Name: D5_S1400_E1245_USSA_LC6_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.12



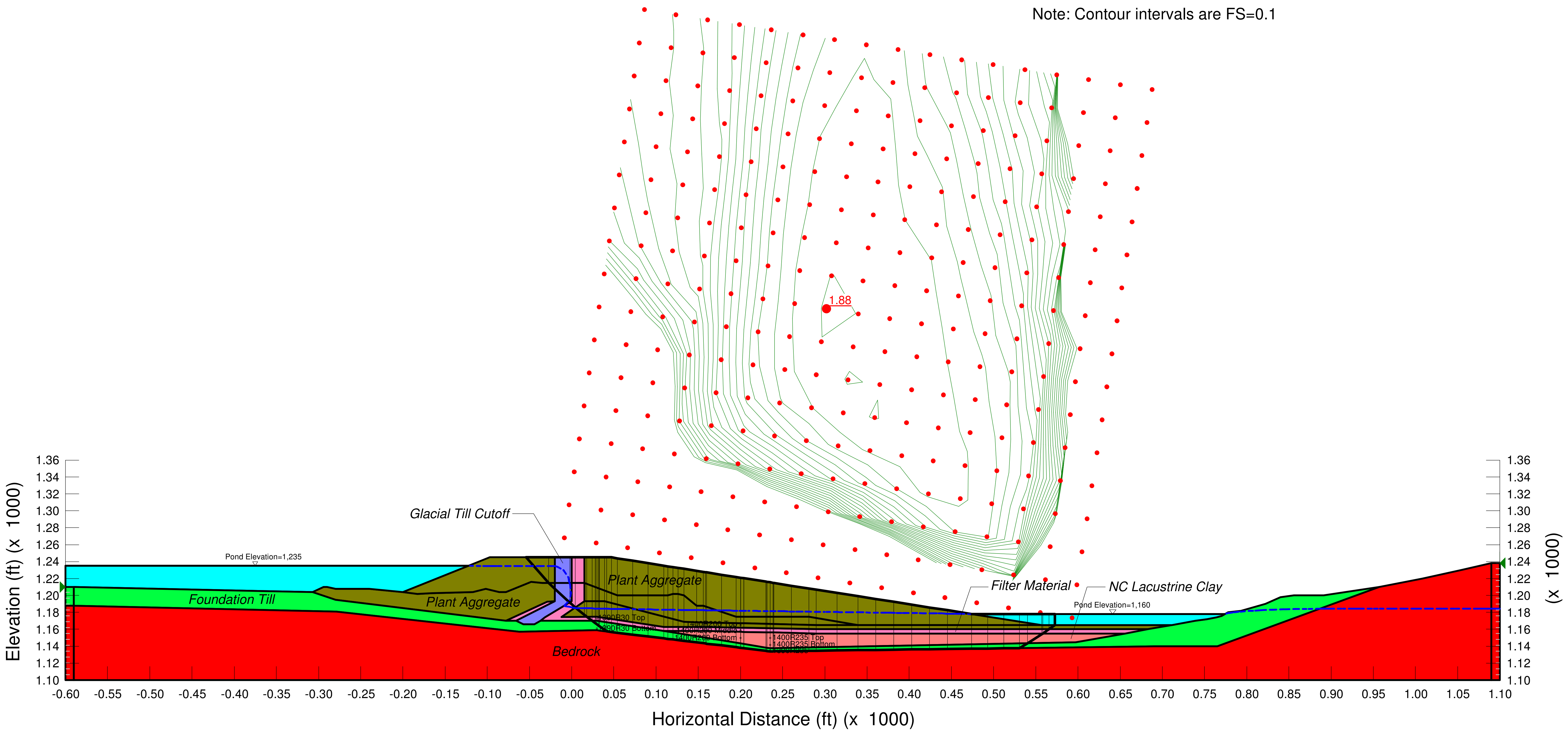
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FM Toe, High Pond
File Name: D5_S1400_E1245_USSA_LC7_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.87



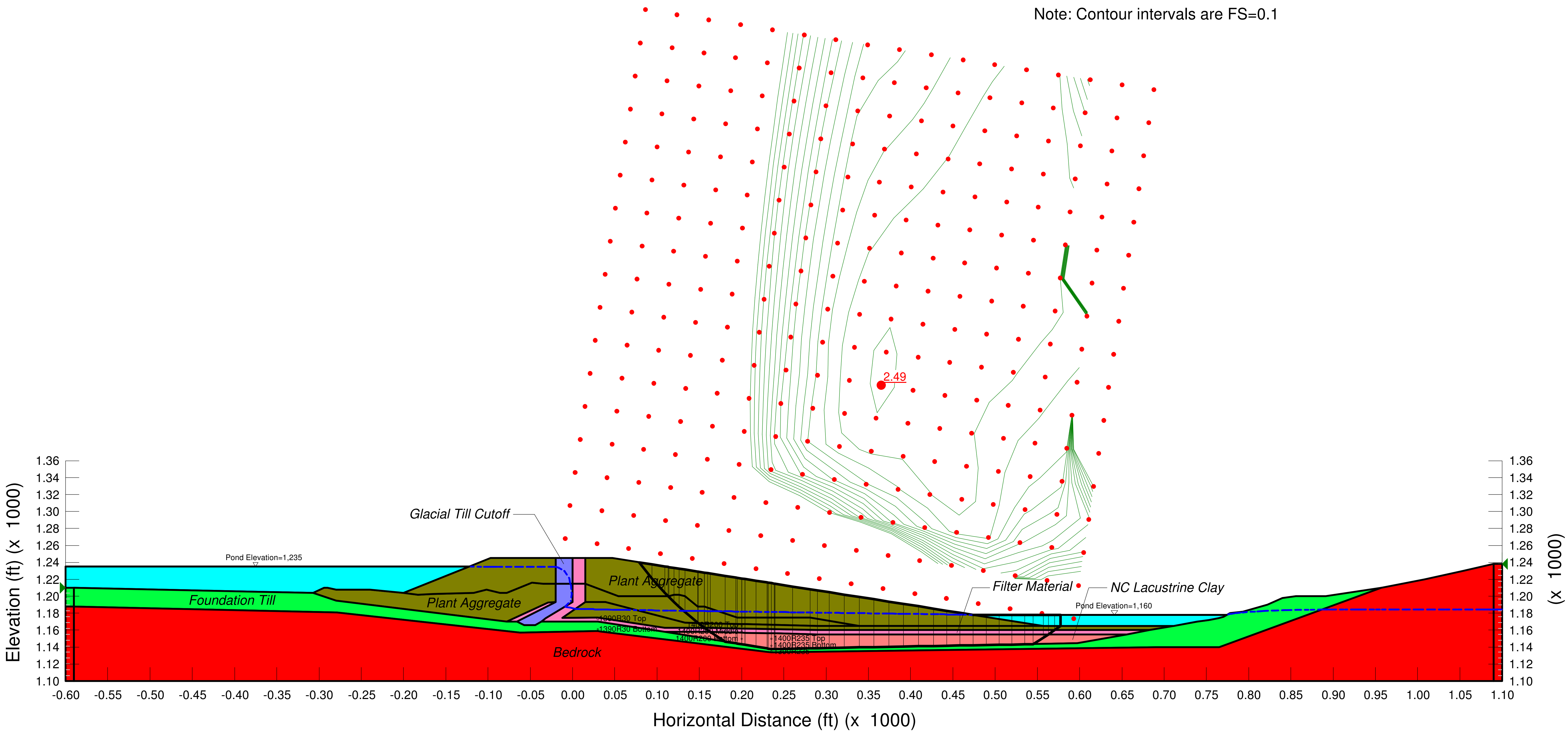
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Low, FM Block, High Pond
File Name: D5_S1400_E1245_USSA_LC7_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.08



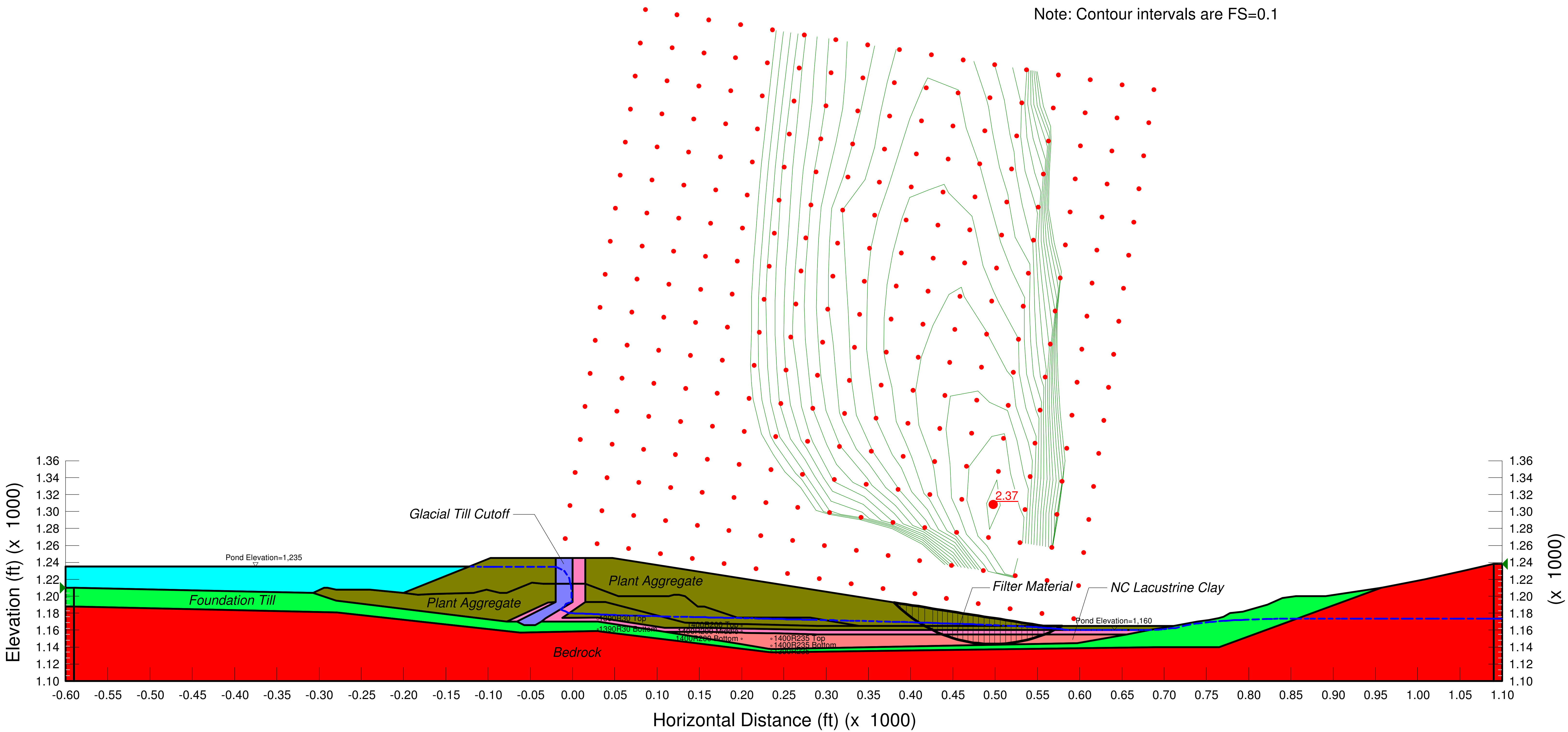
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FM Toe, High Pond
File Name: D5_S1400_E1245_USSA_LC8_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 1.88



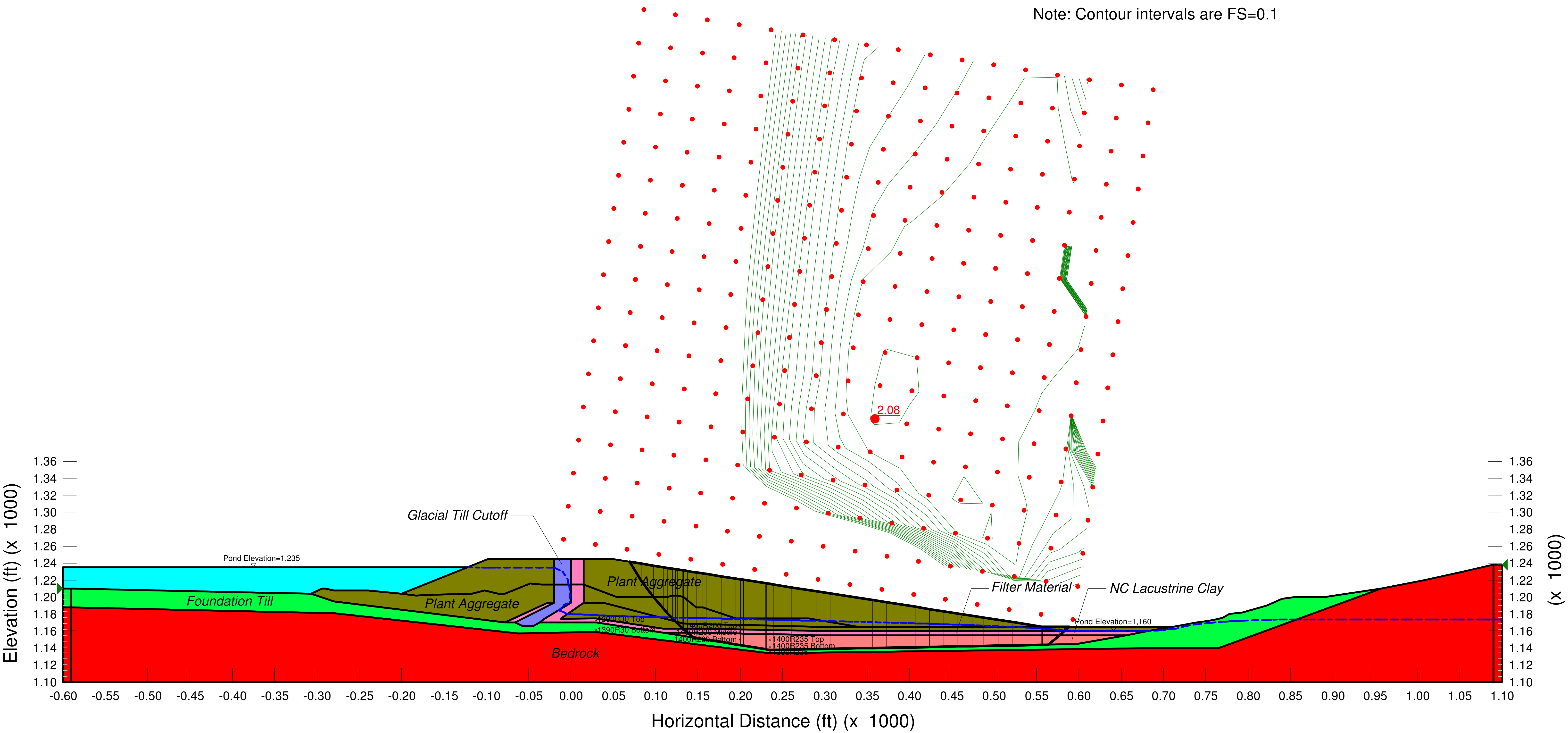
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), USSA, LC TXC Average, FM Block, High Pond
File Name: D5_S1400_E1245_USSA_LC8_FM3_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.49



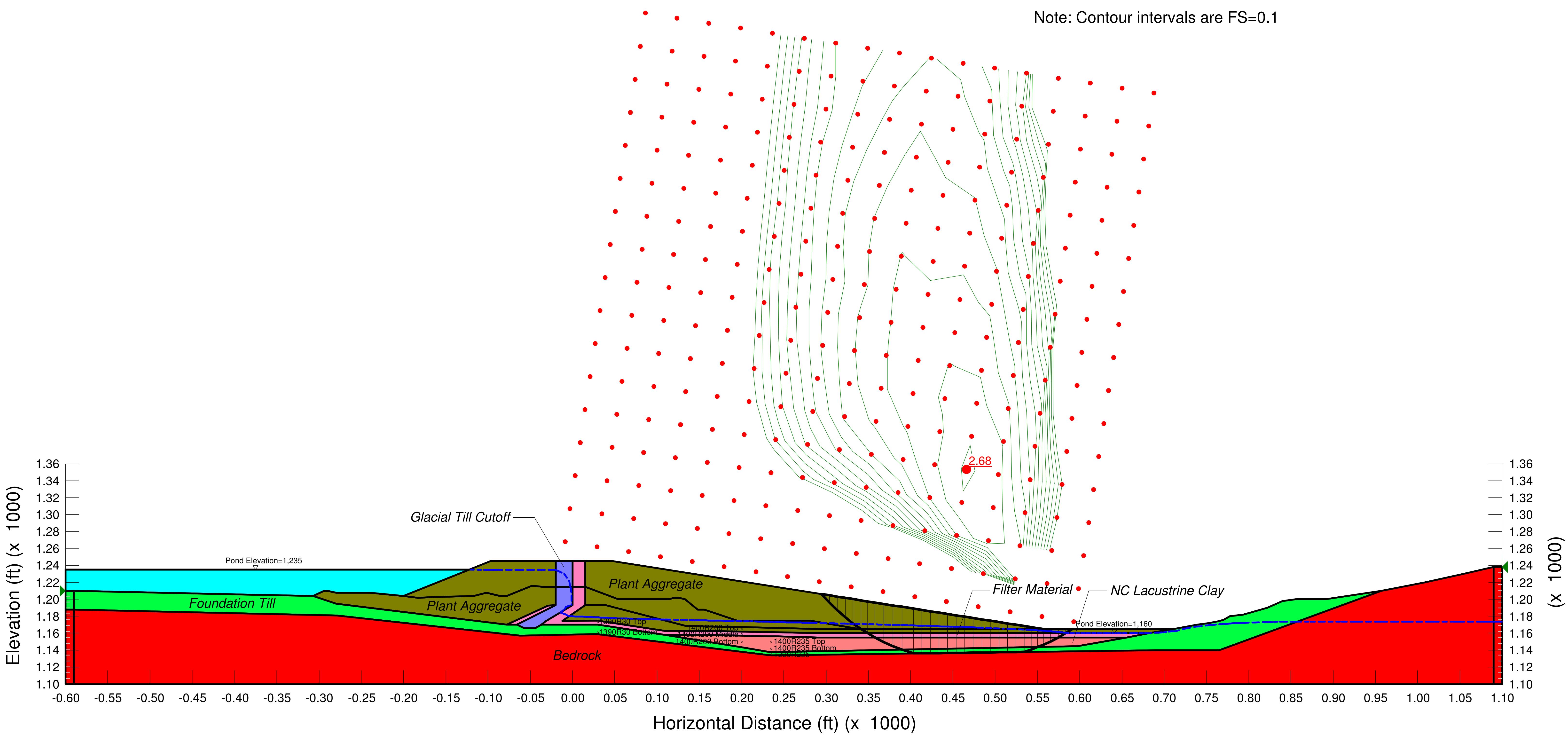
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Toe, Low Pond
File Name: D5_S1400_E1245_ESSA_LC1_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.37



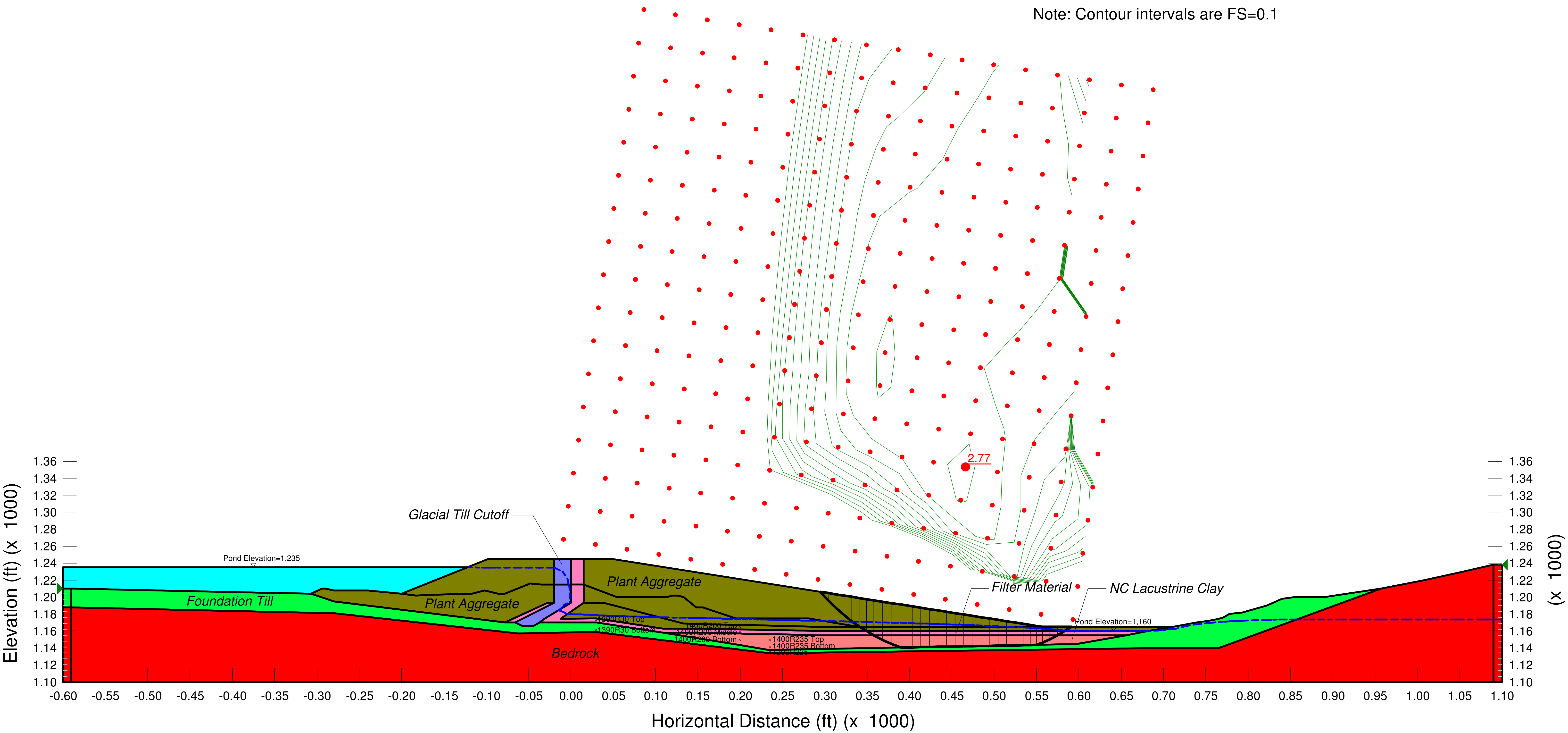
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Block, Low Pond
File Name: D5_S1400_E1245_ESSA_LC1_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.08



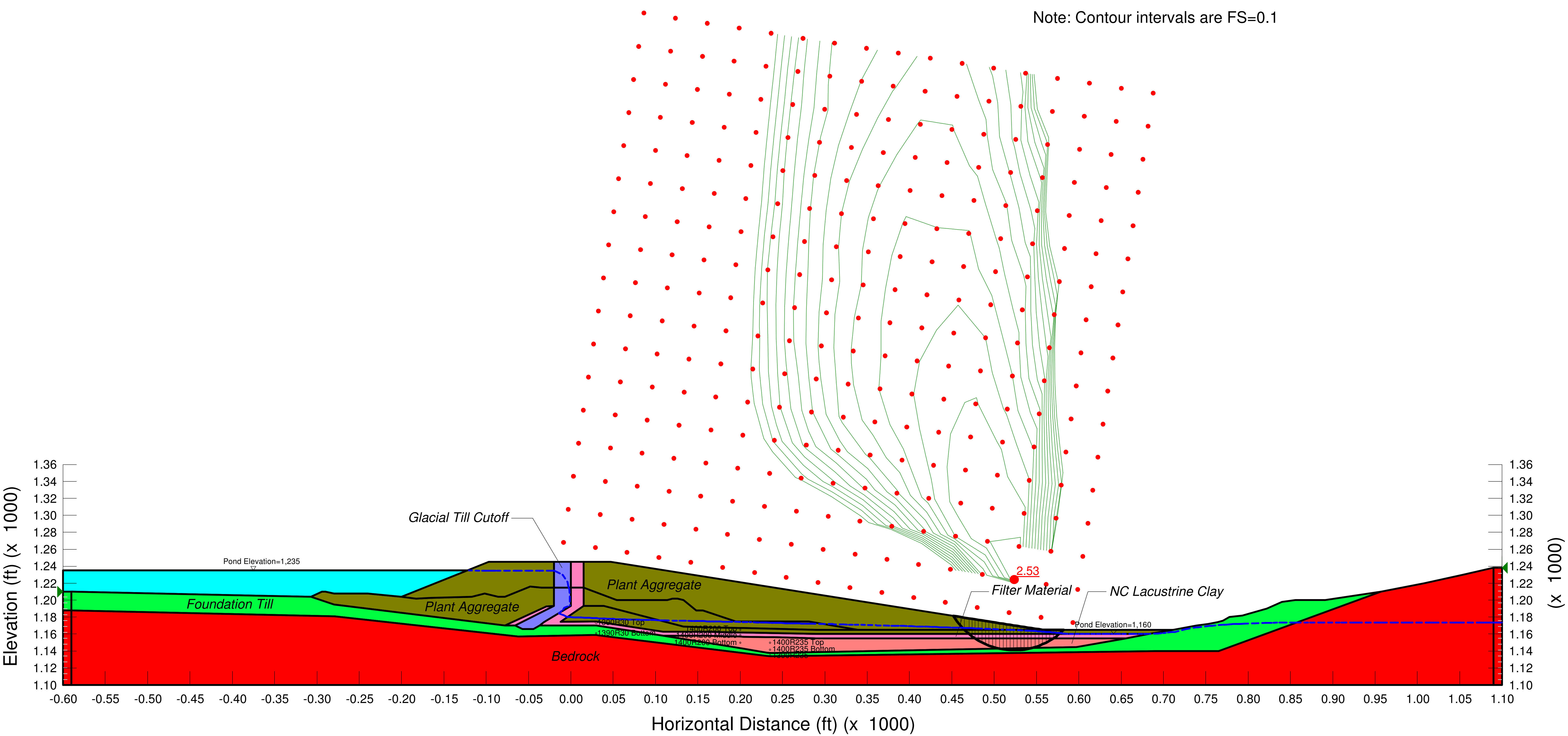
Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Toe, Low Pond
File Name: D5_S1400_E1245_ESSA_LC2_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.68



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Block, Low Pond
File Name: D5_S1400_E1245_ESSA_LC2_FM3_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.77



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Toe, Low Pond
File Name: D5_S1400_E1245_ESSA_LC3_FM1_Low.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.53



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Block, Low Pond
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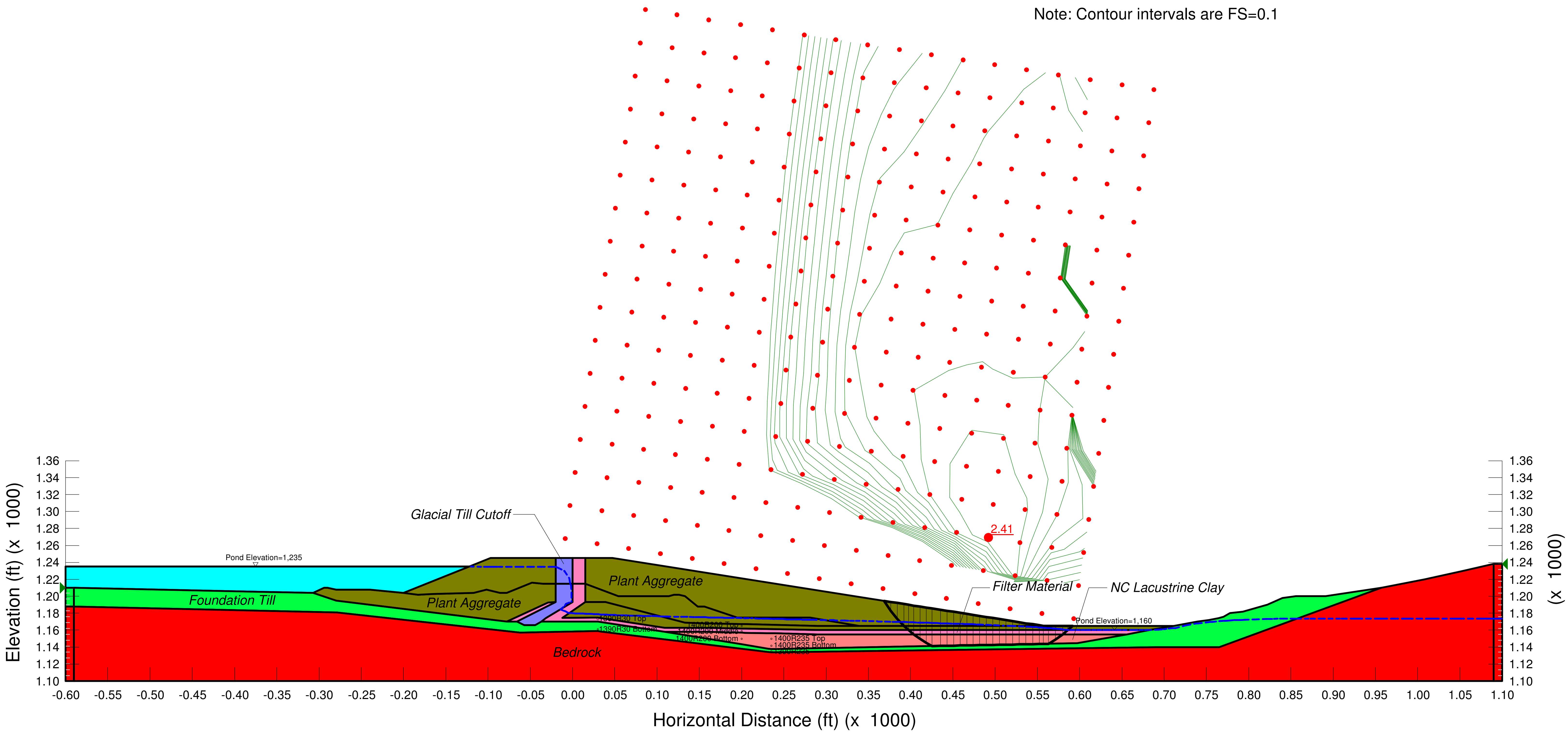
Last Saved Date: 8/21/2008
Factor of Safety: 2.41



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Toe, Low Pond
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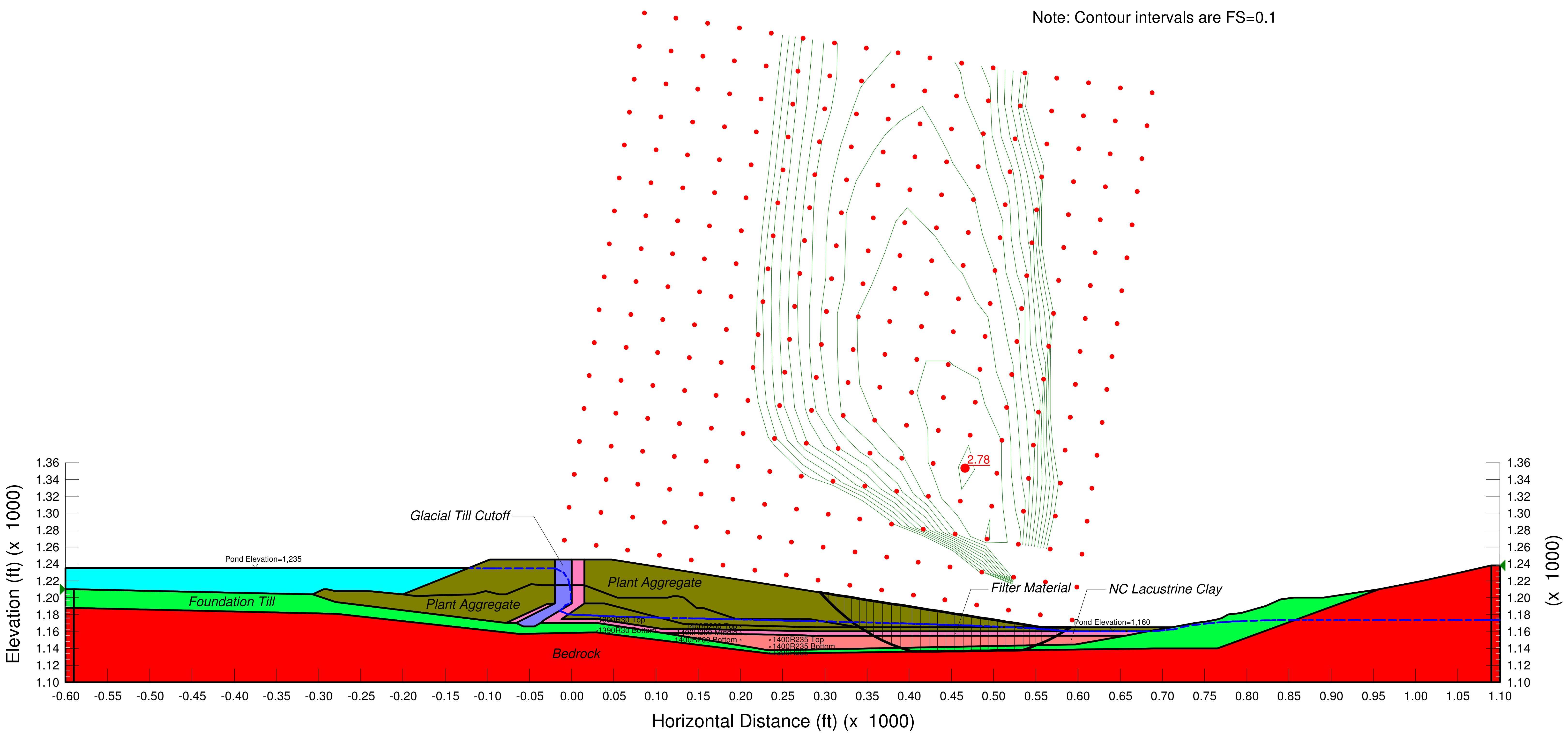
Factor of Safety: 2.78



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
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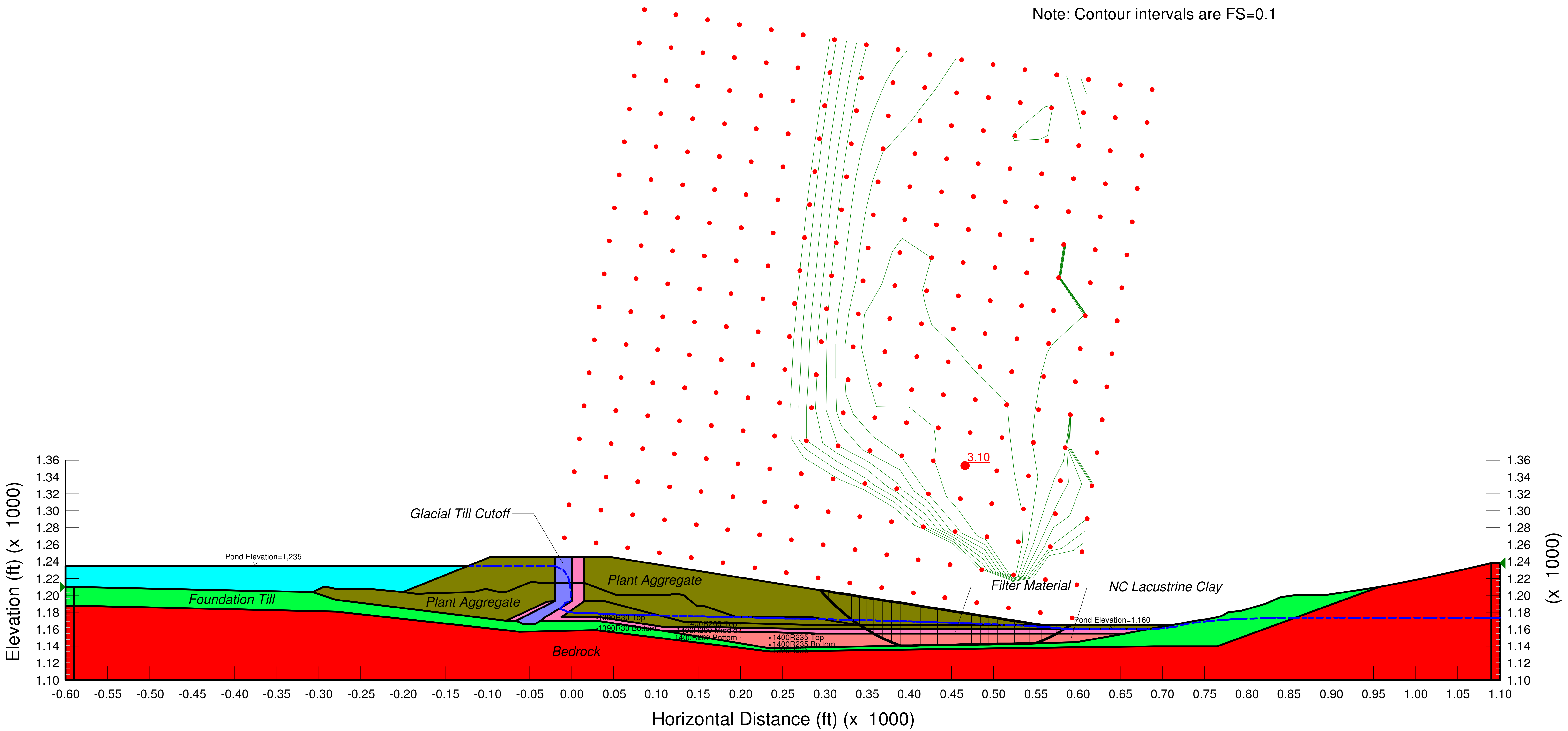
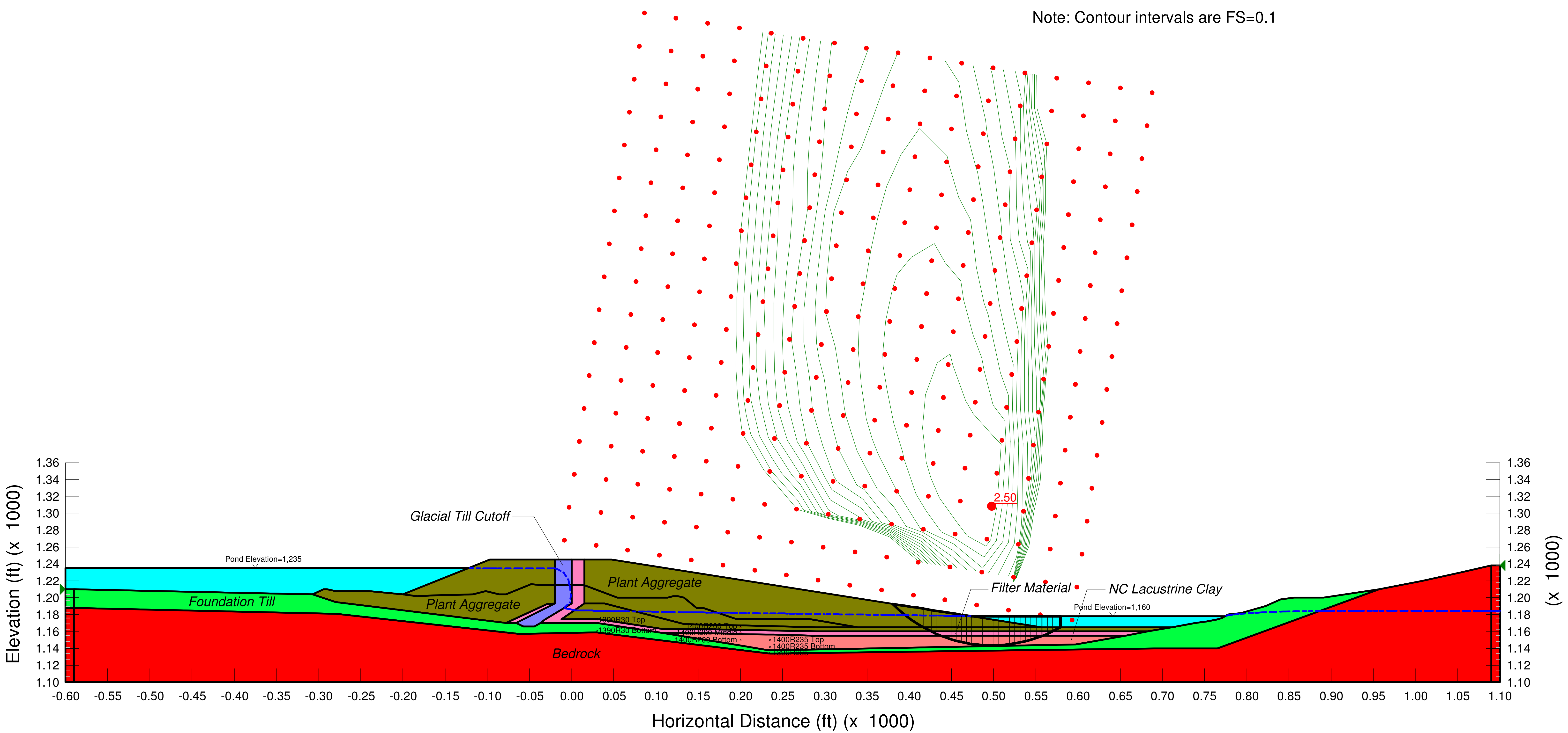
Factor of Safety: 3.10



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Toe, High Pond
File Name: D5_S1400_E1245_ESSA_LC1_FM1_High.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.50



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Intermediate Geometry (El. 1245), ESSA, LC DSS Low, FM Block, High Pond
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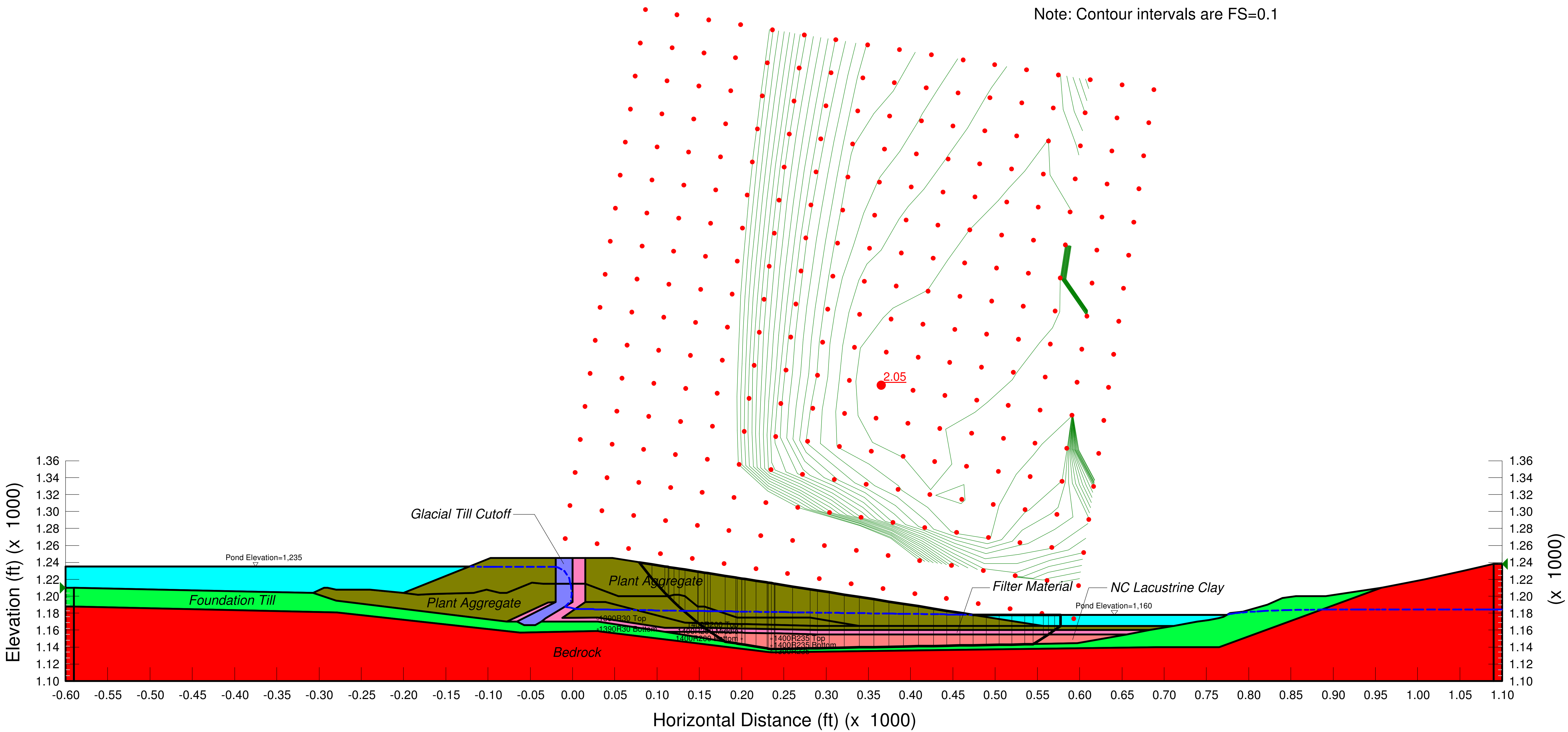
Factor of Safety: 2.05



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC DSS Average, FM Toe, High Pond
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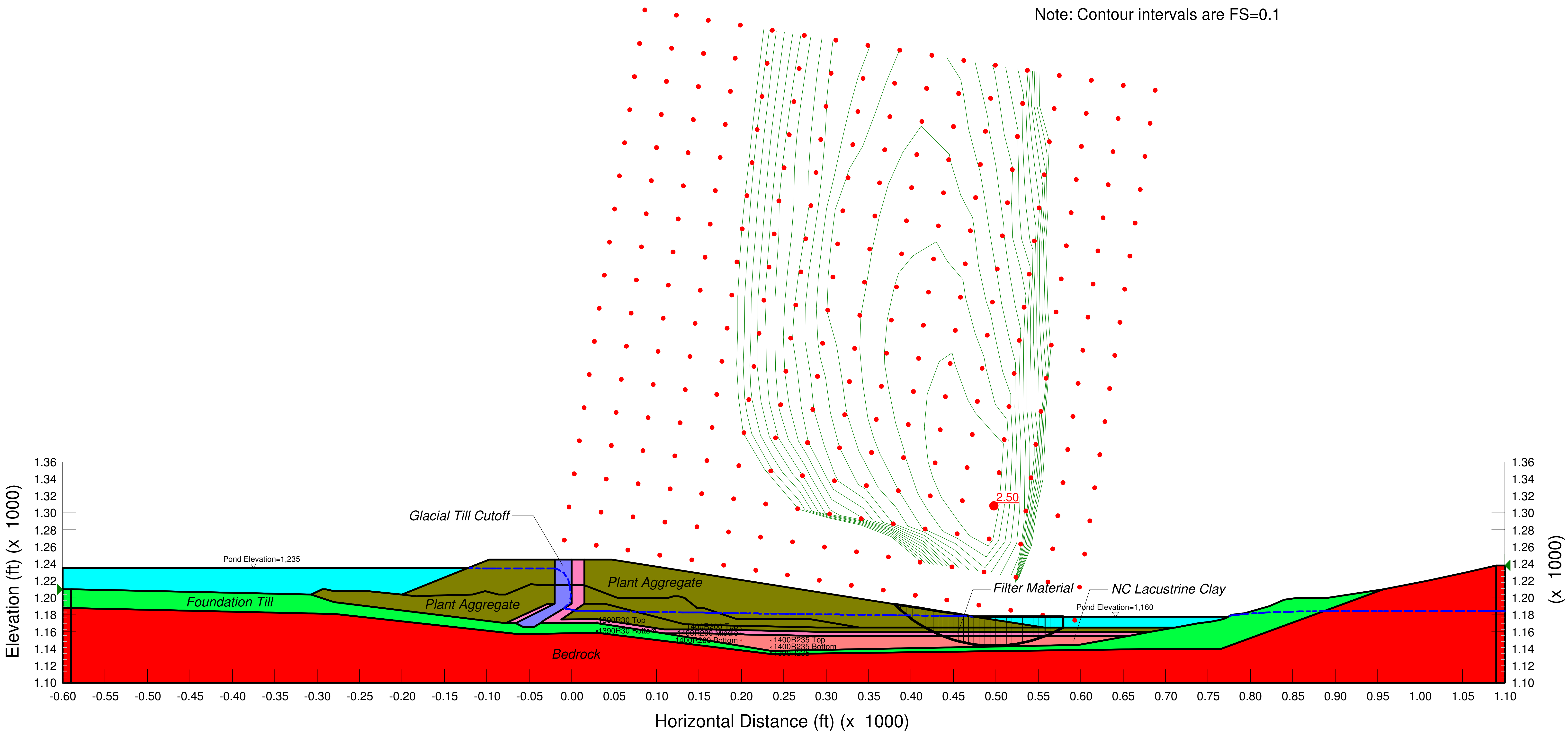
Factor of Safety: 2.50



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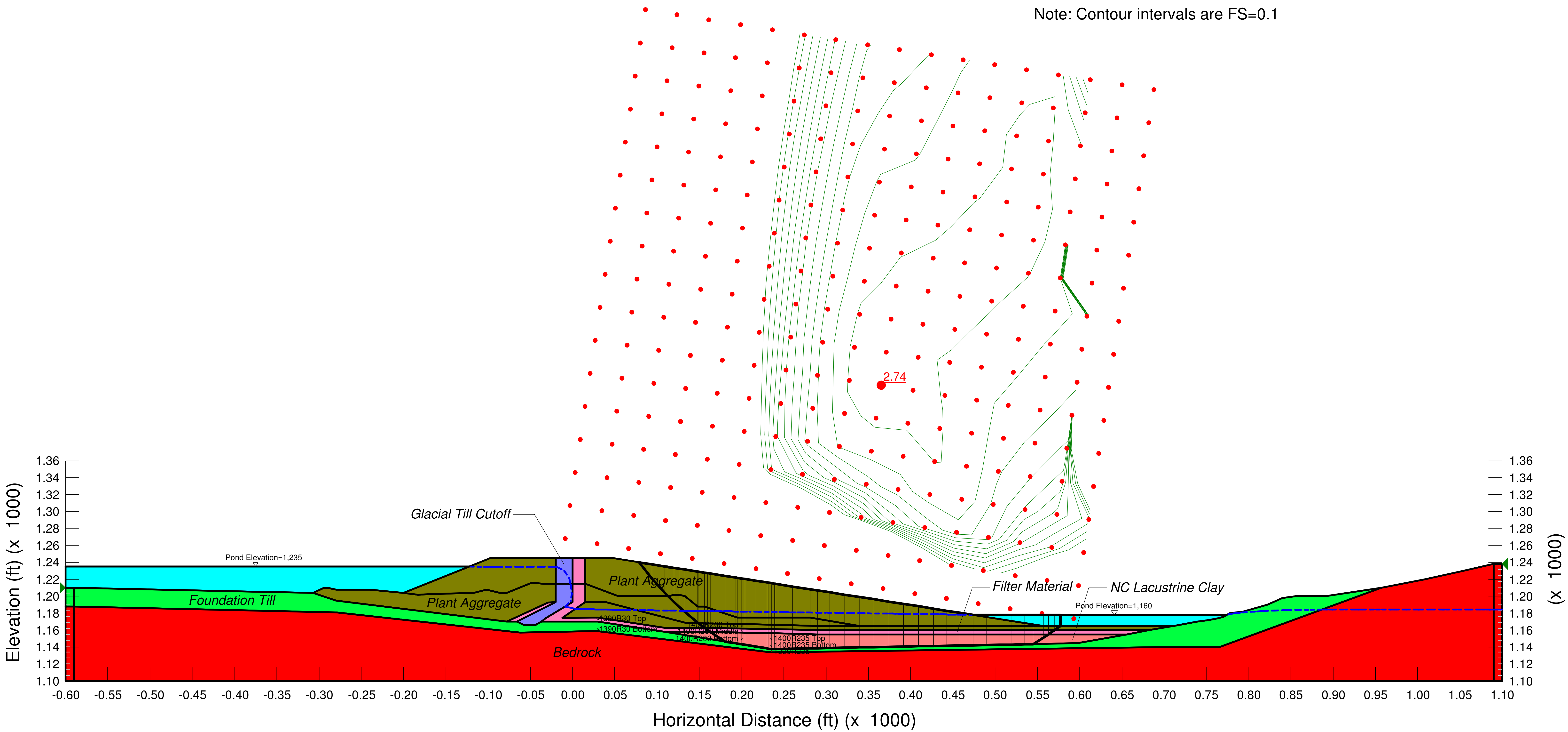
Last Saved Date: 8/21/2008
Factor of Safety: 2.74



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Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Toe, High Pond
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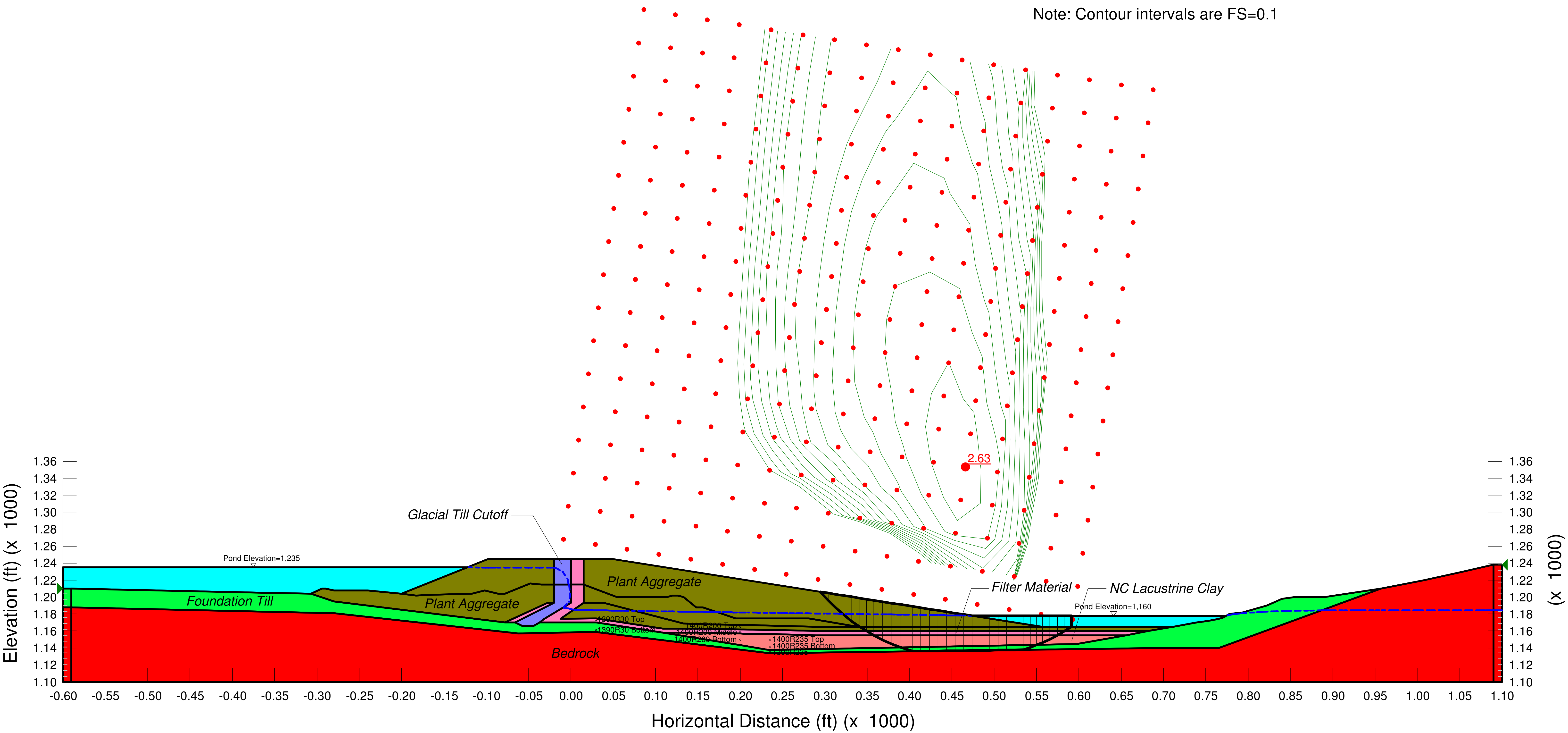
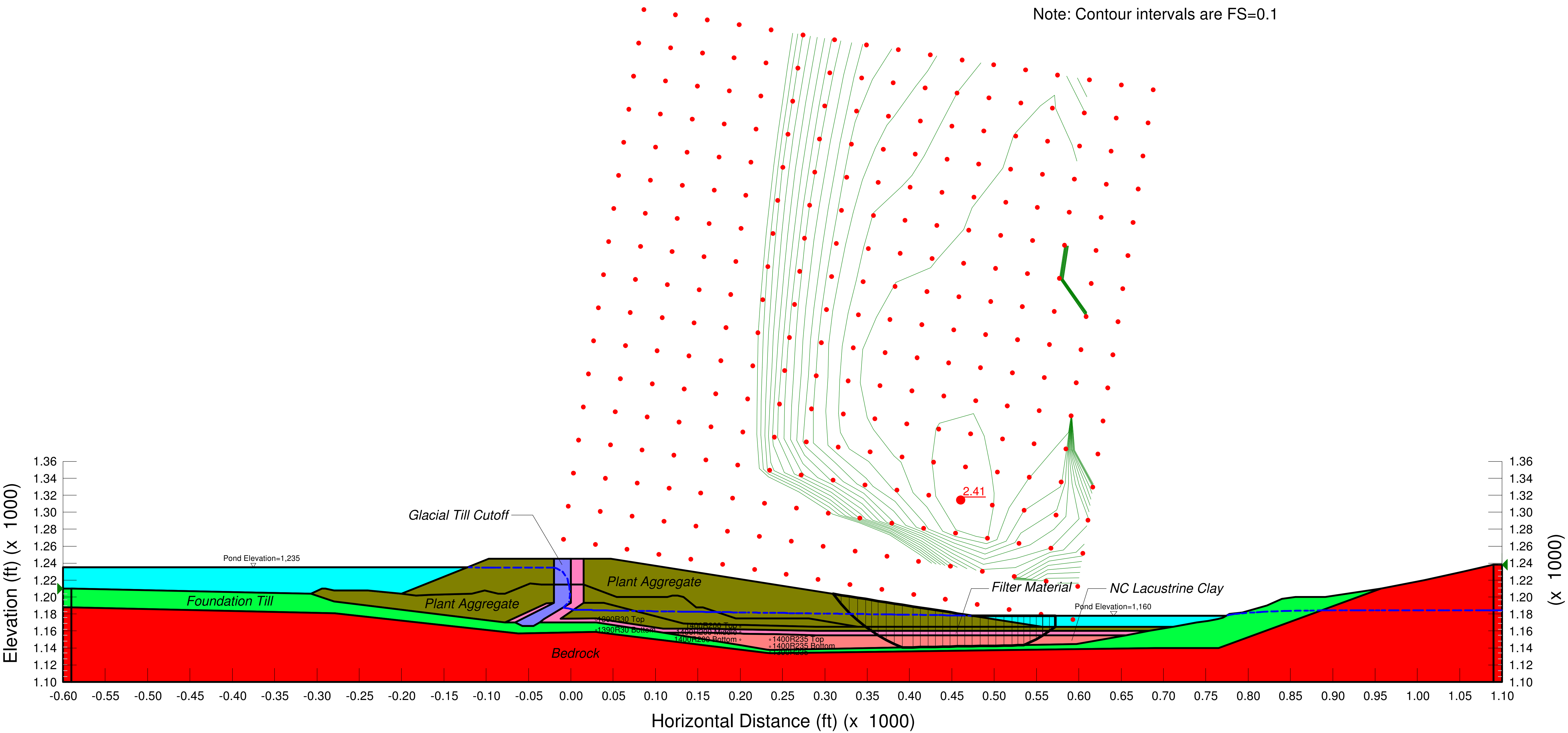
Last Saved Date: 8/21/2008
Factor of Safety: 2.63



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Low, FM Block, High Pond
_File Name: D5_S1400_E1245_ESSA_LC3_FM3_High.gsz_
Last Saved Date: 8/21/2008
Factor of Safety: 2.41



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Toe, High Pond
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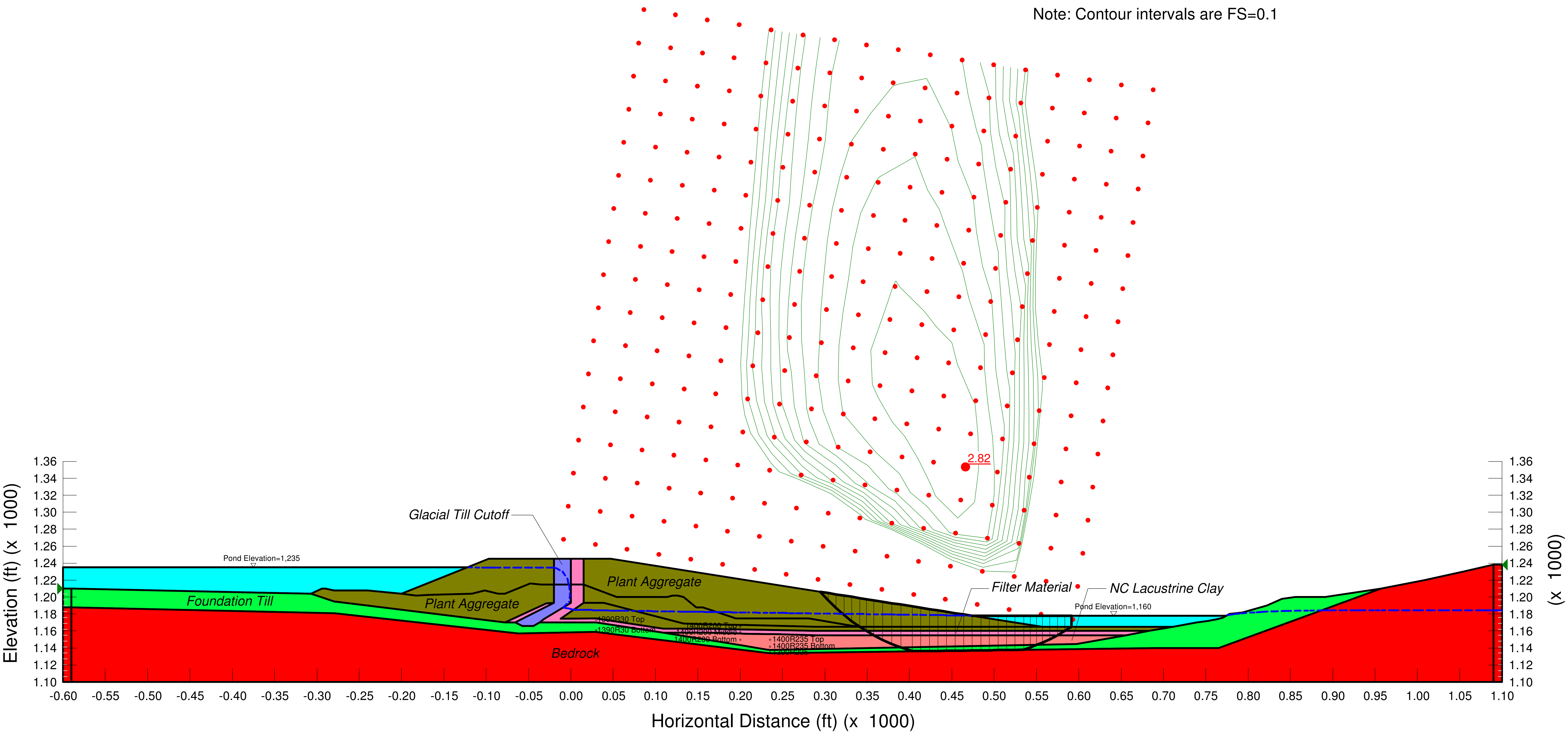
Last Saved Date: 8/21/2008
Factor of Safety: 2.82



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Intermediate Geometry (El. 1245), ESSA, LC TXC Average, FM Block, High Pond
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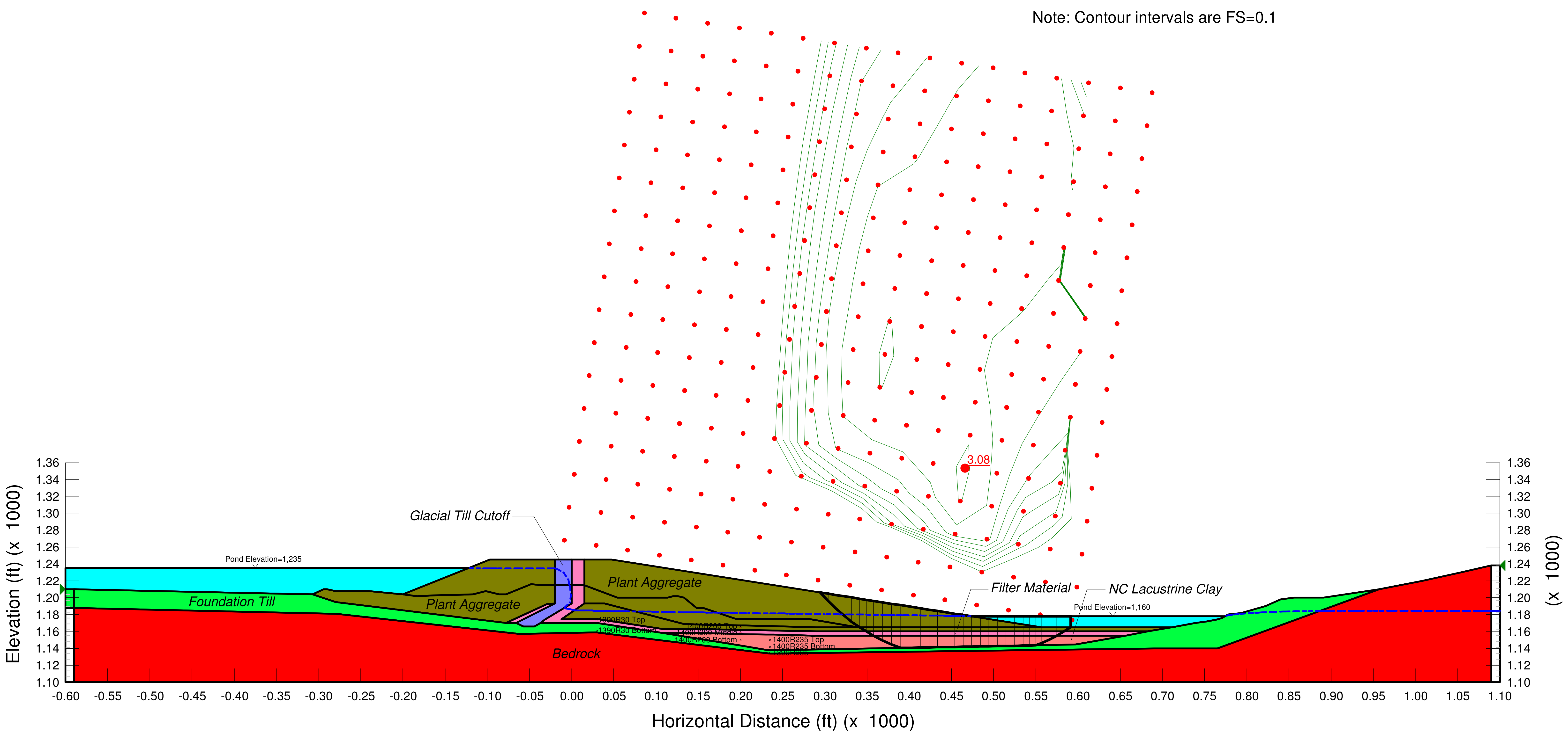
Factor of Safety: 3.08



Proposed Geometry El. 1,315 feet

Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FM Toe
File Name: D5_S1400_E1315_USSA_LC5_FM1.gsz
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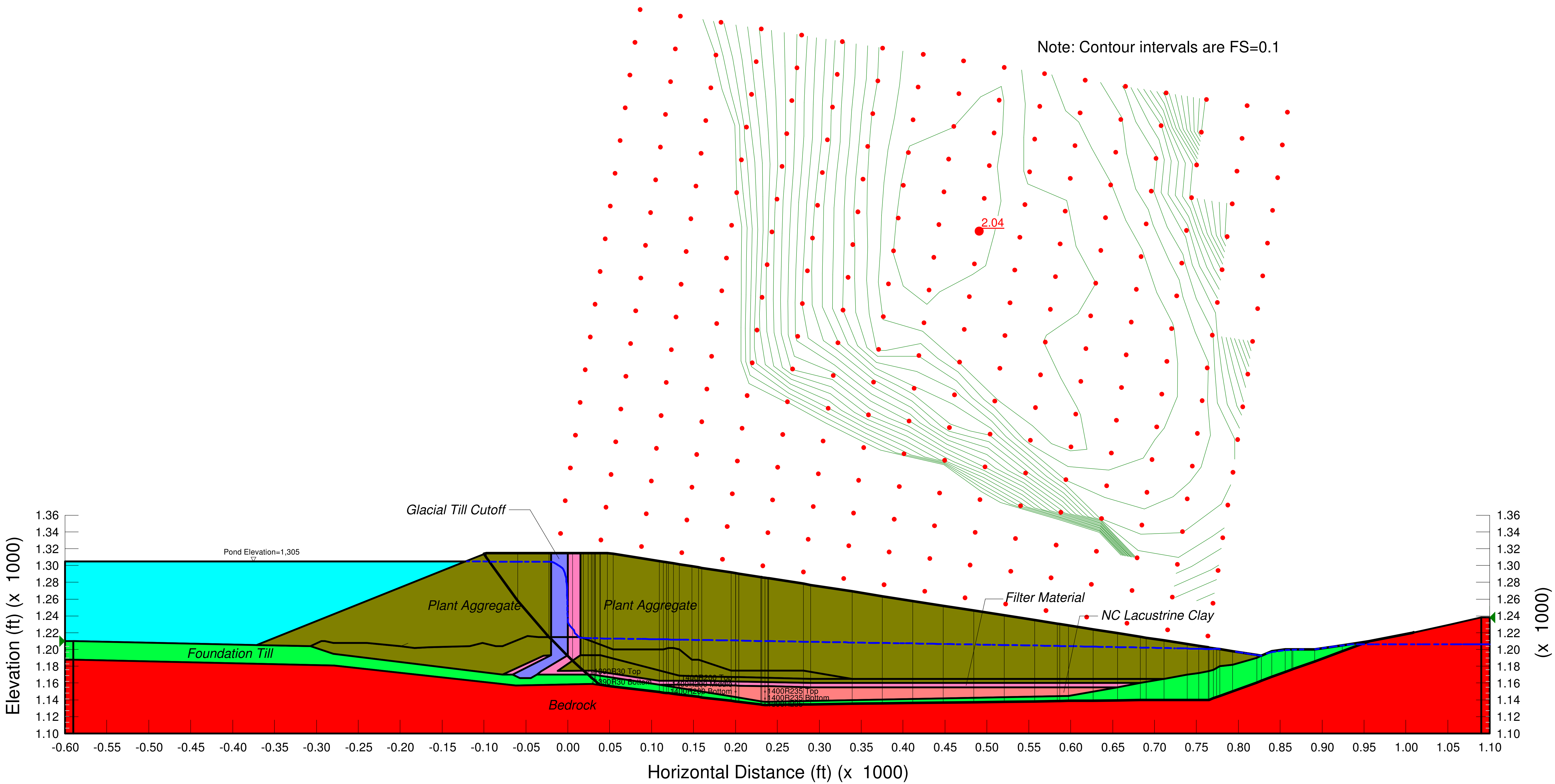
Factor of Safety: 2.04



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Low, FM Block
File Name: D5_S1400_E1315_USSA_LC5_FM3.gsz
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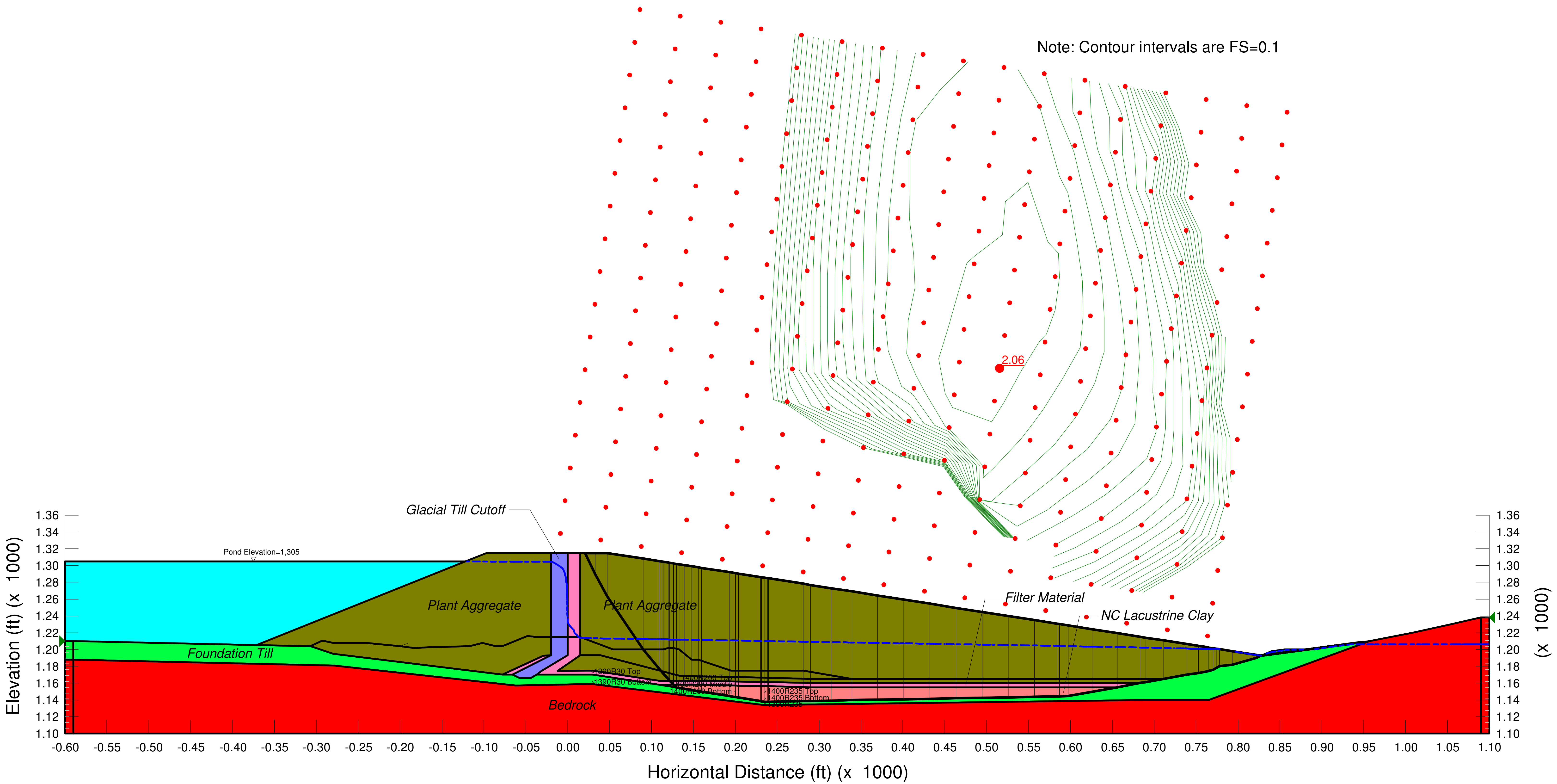
Factor of Safety: 2.06



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Ultimate Geometry (El. 1315), USSA, LC DSS Average, FM Toe
File Name: D5_S1400_E1315_USSA_LC6_FM1.gsz
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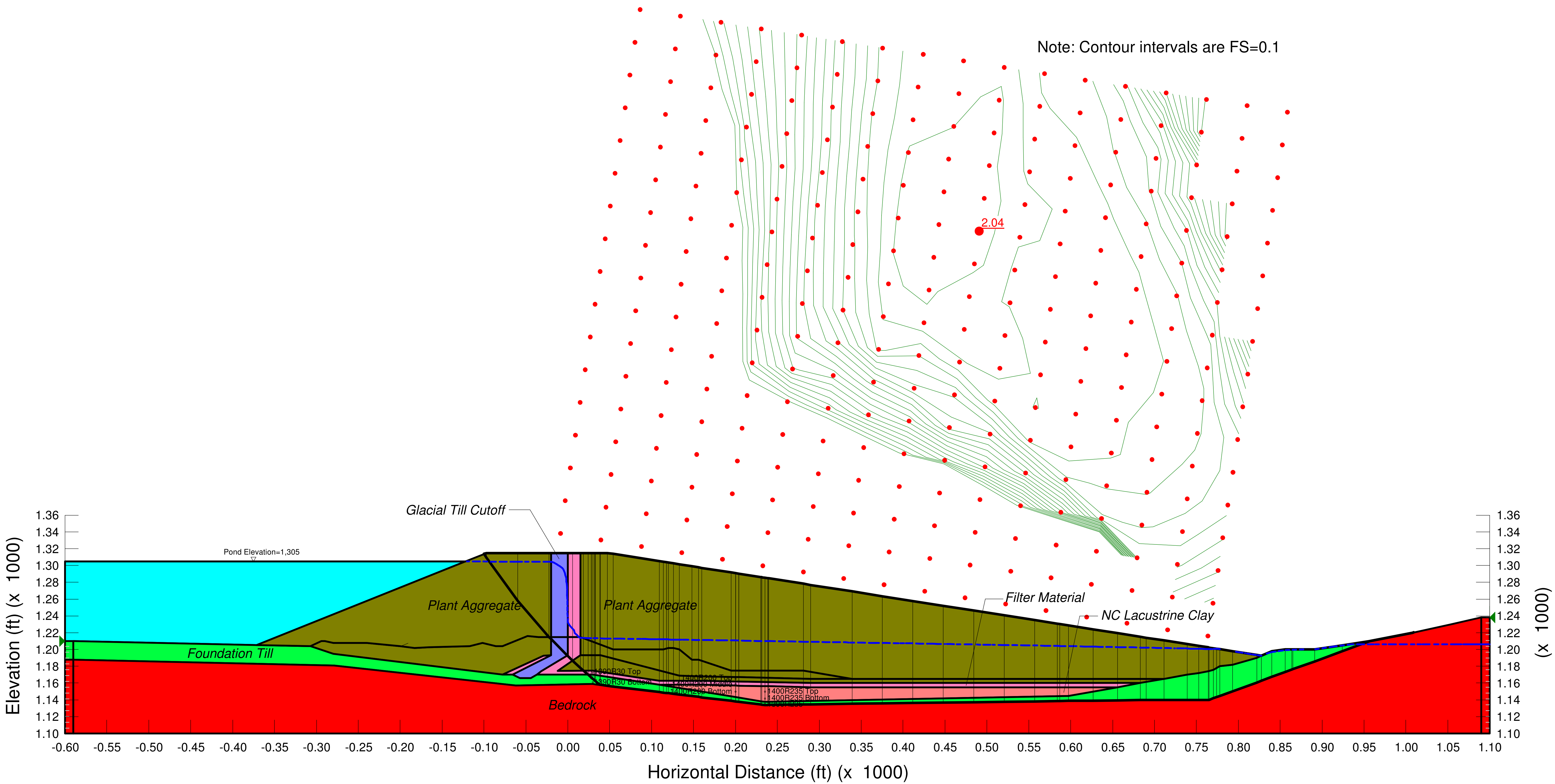
Factor of Safety: 2.04



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC DSS Average, FM Block
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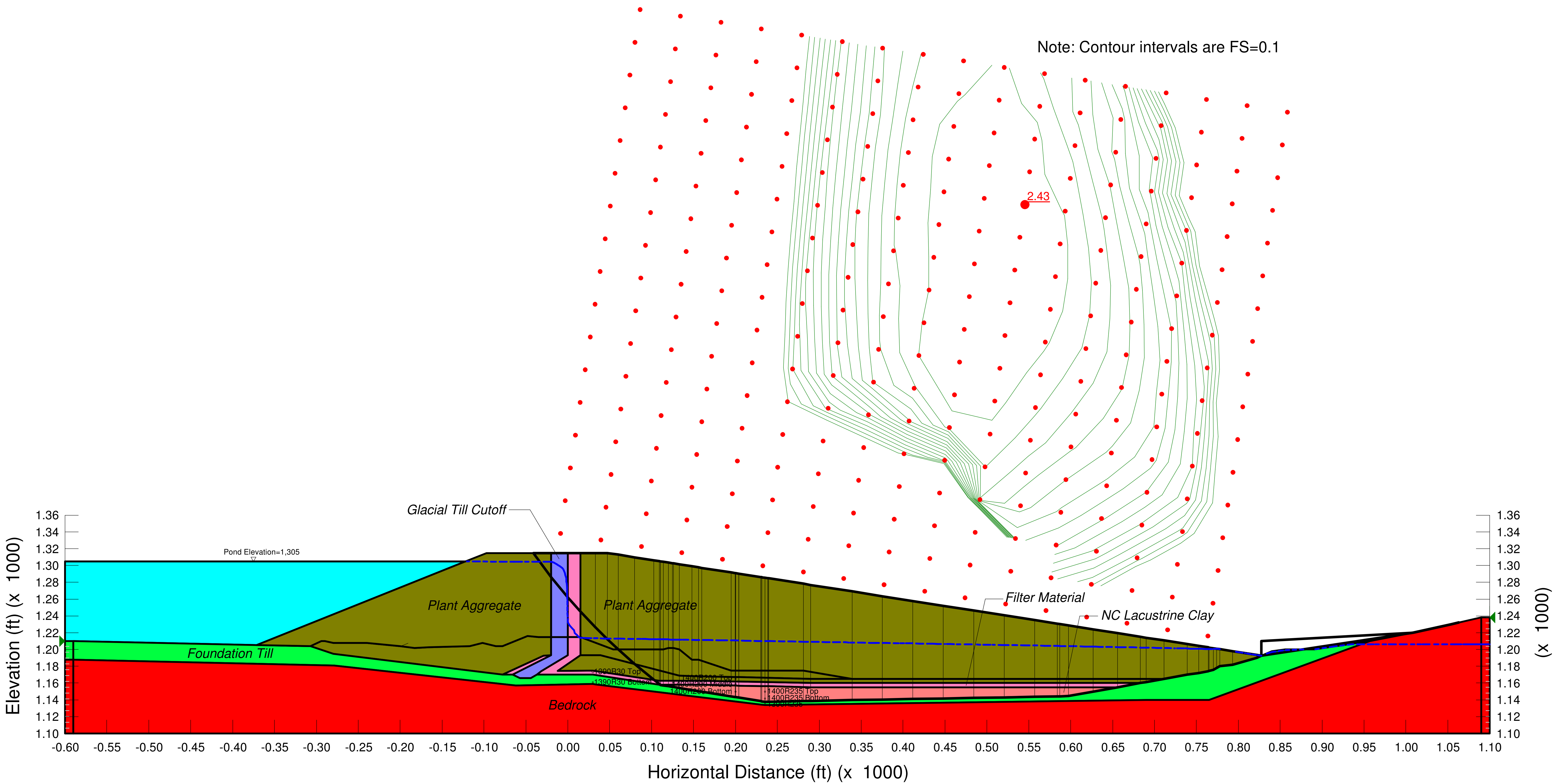
Factor of Safety: 2.43



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Ultimate Geometry (El. 1315), USSA, LC TXC Low, FM Toe
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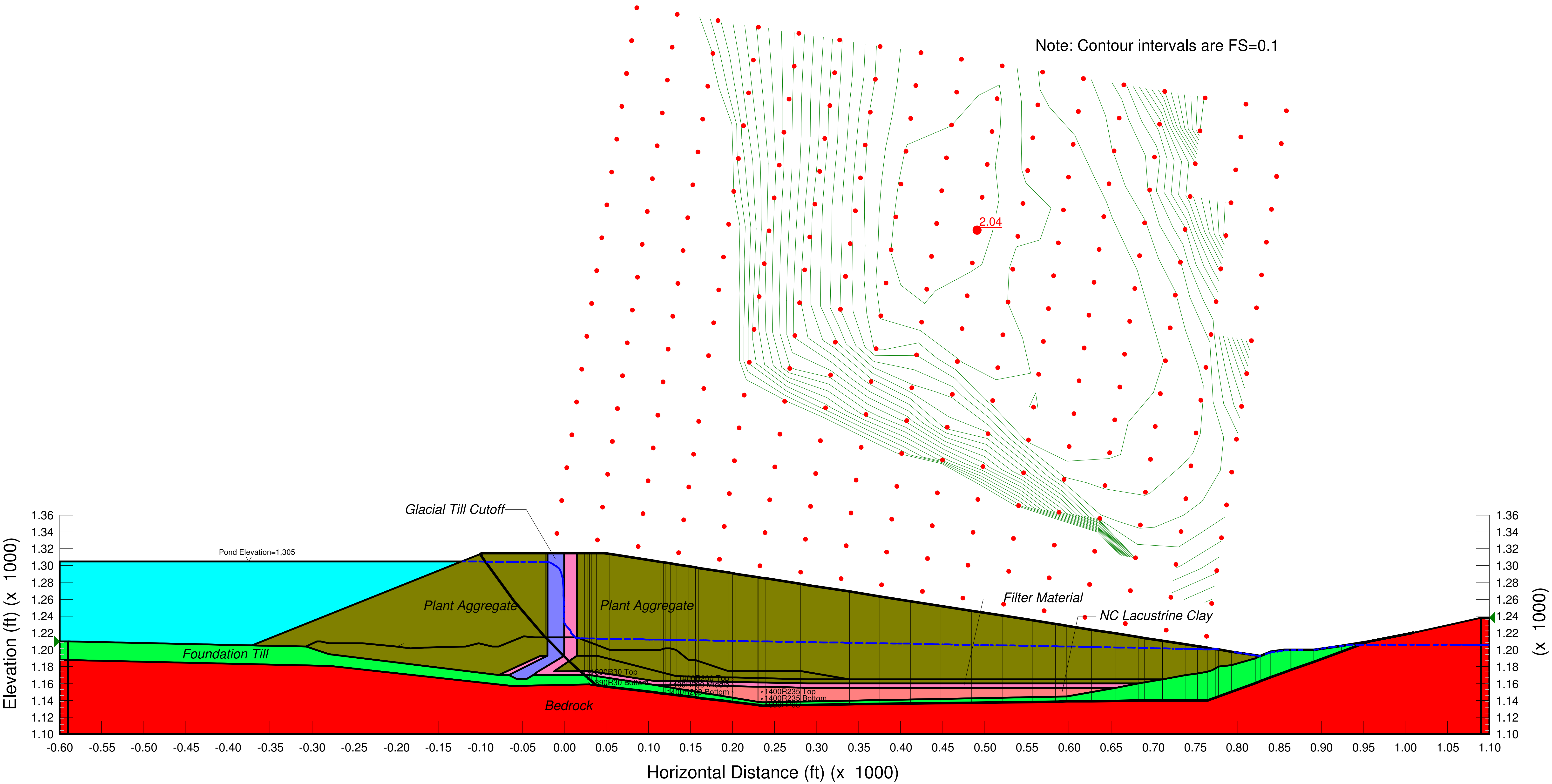
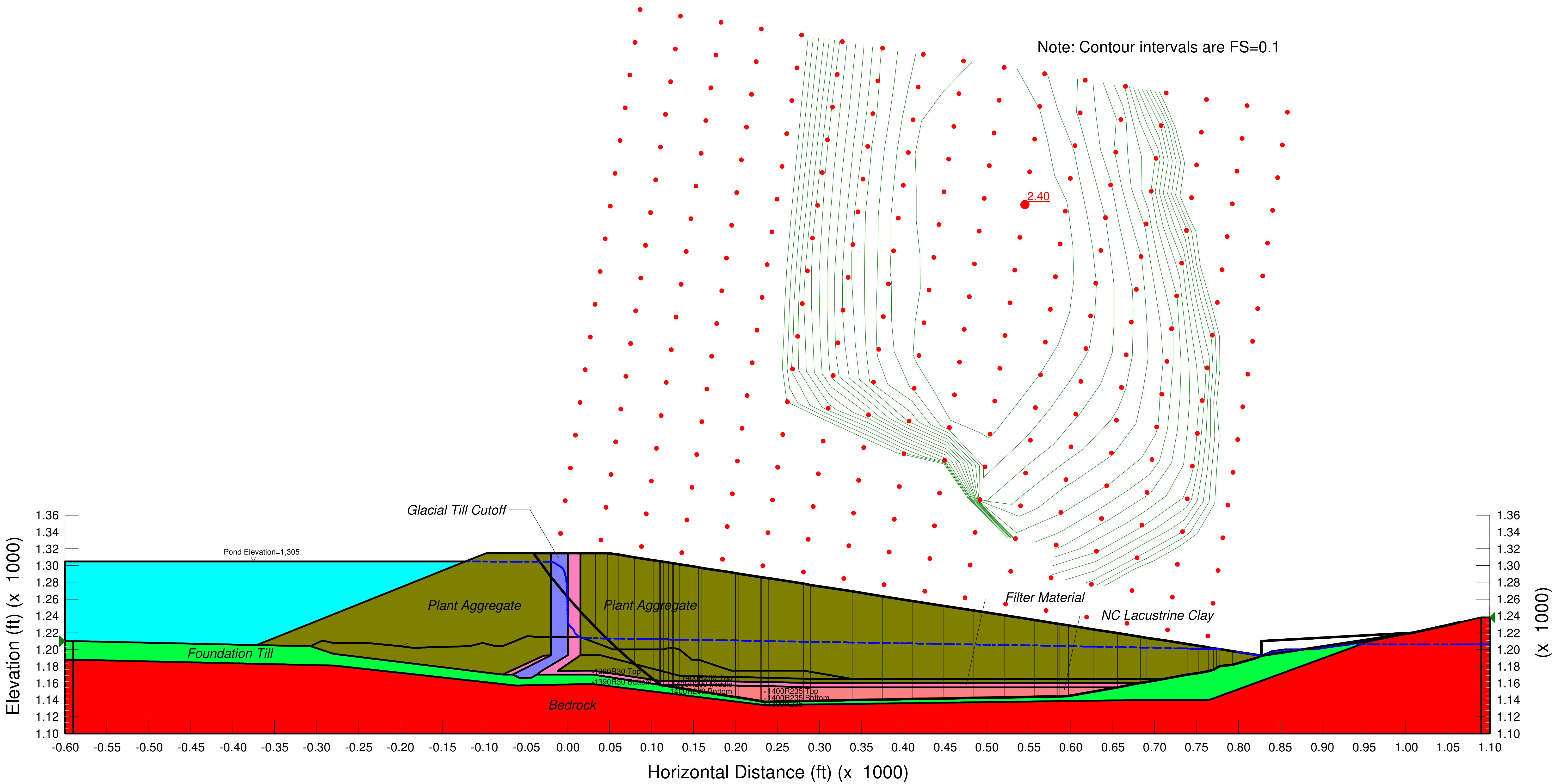
Factor of Safety: 2.04



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Low, FM Block
File Name: D5_S1400_E1315_USSA_LC7_FM3.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.40



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FM Toe
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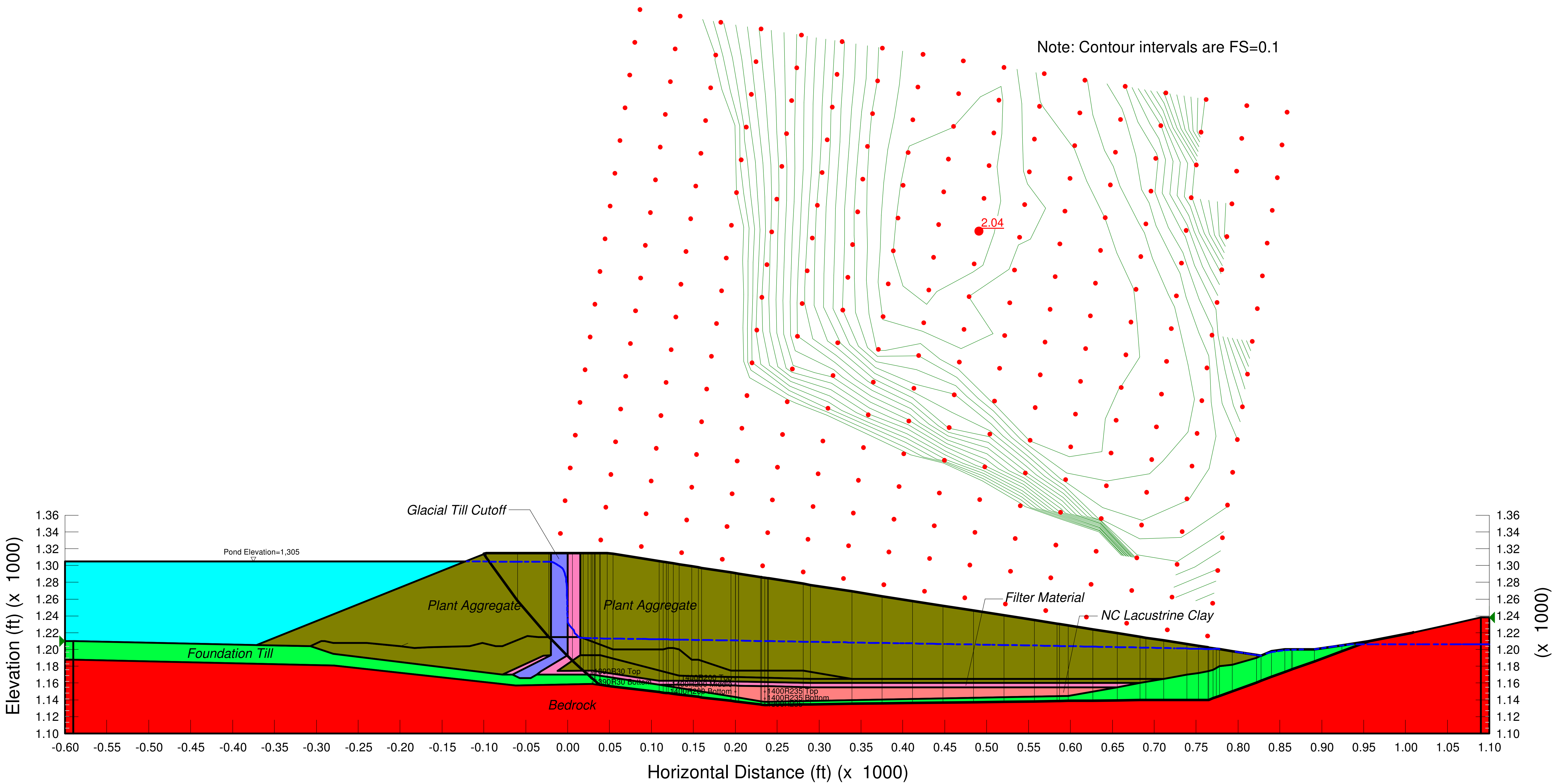
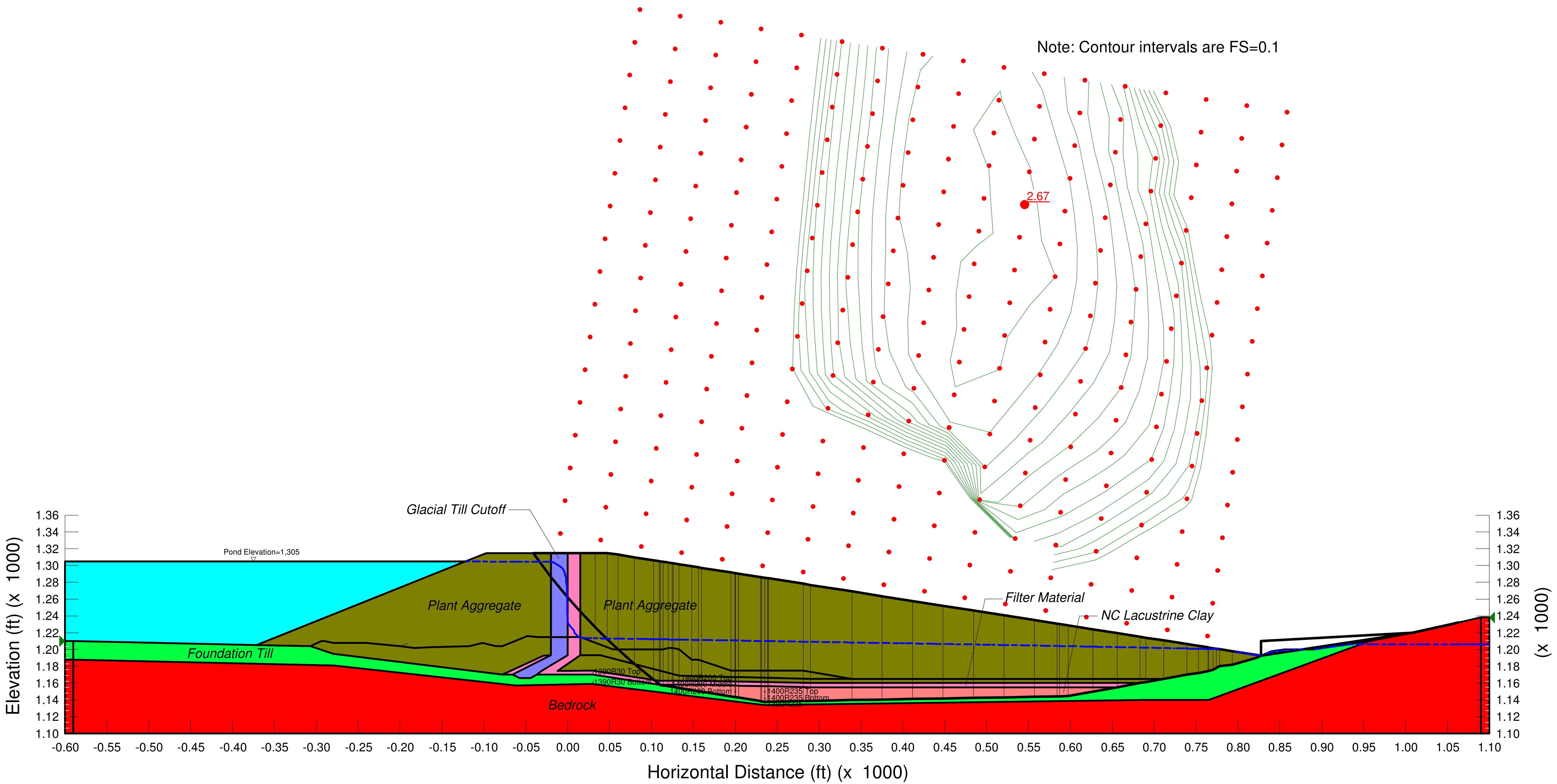
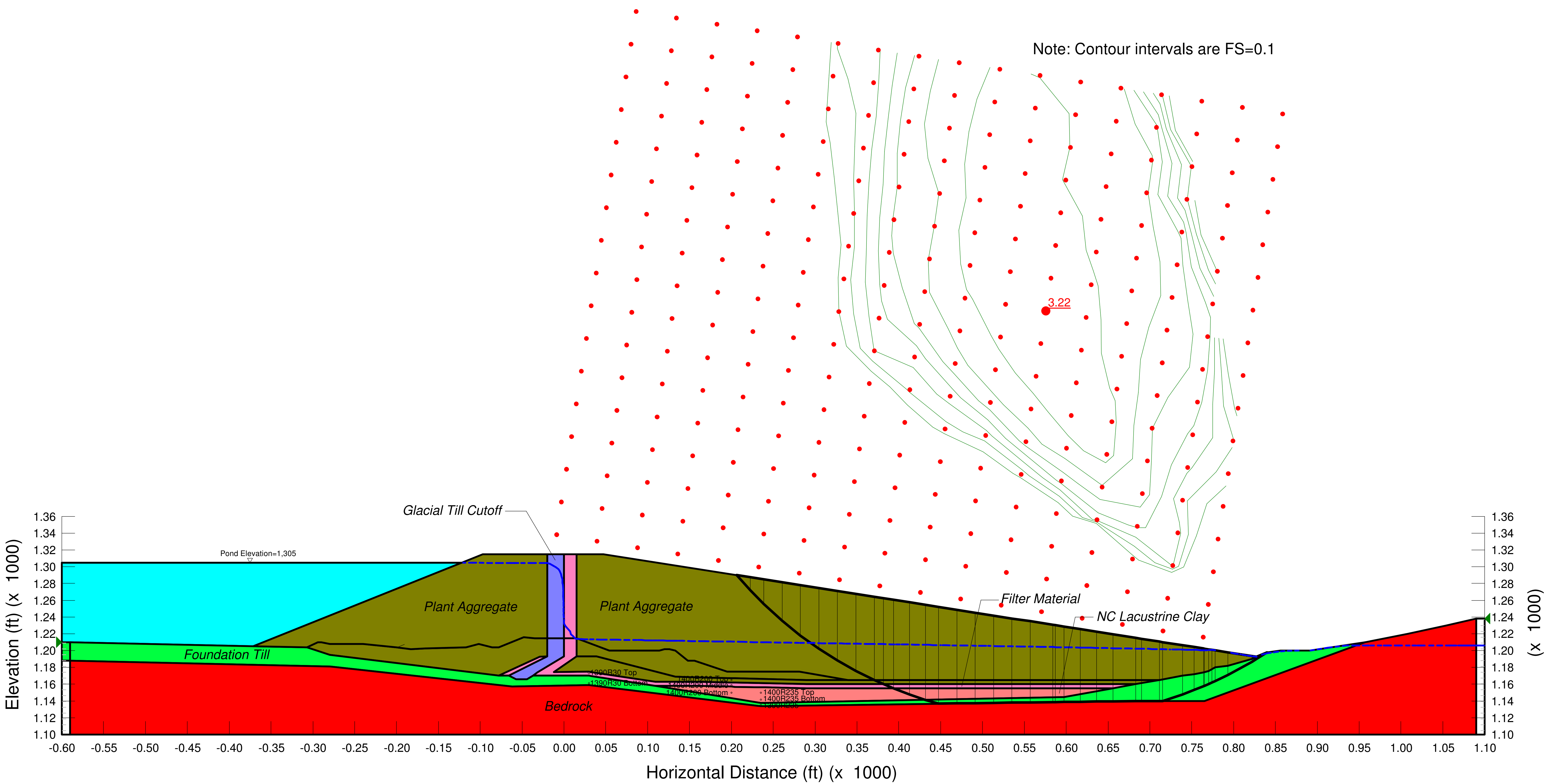
Factor of Safety: 2.04



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), USSA, LC TXC Average, FM Block
File Name: D5_S1400_E1315_USSA_LC8_FM3.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 2.67



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Low, FM Toe
File Name: D5_S1400_E1315_ESSA_LC1_FM1.gsz
Last Saved Date: 8/21/2008
Factor of Safety: 3.22



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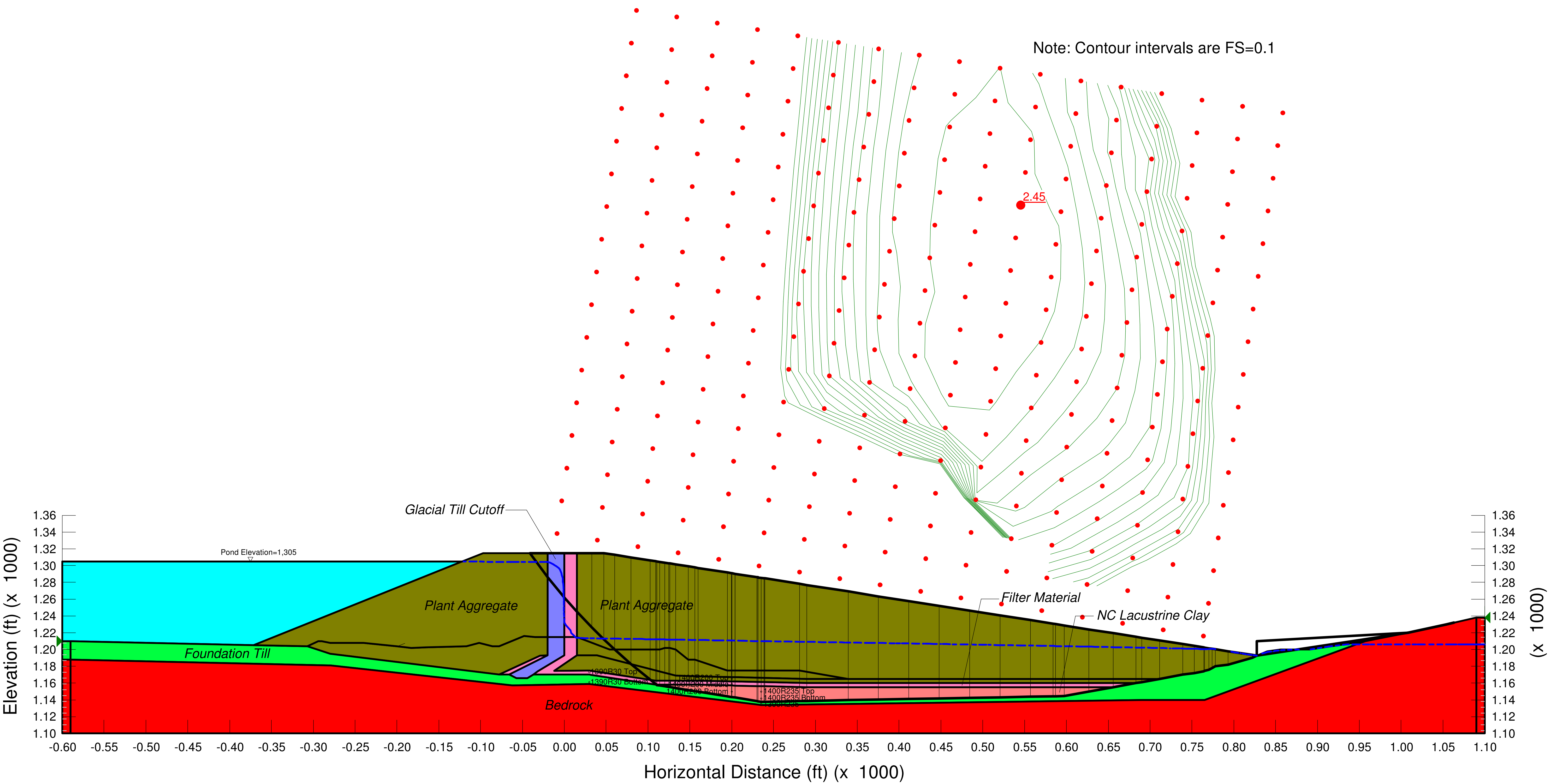

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Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Toe
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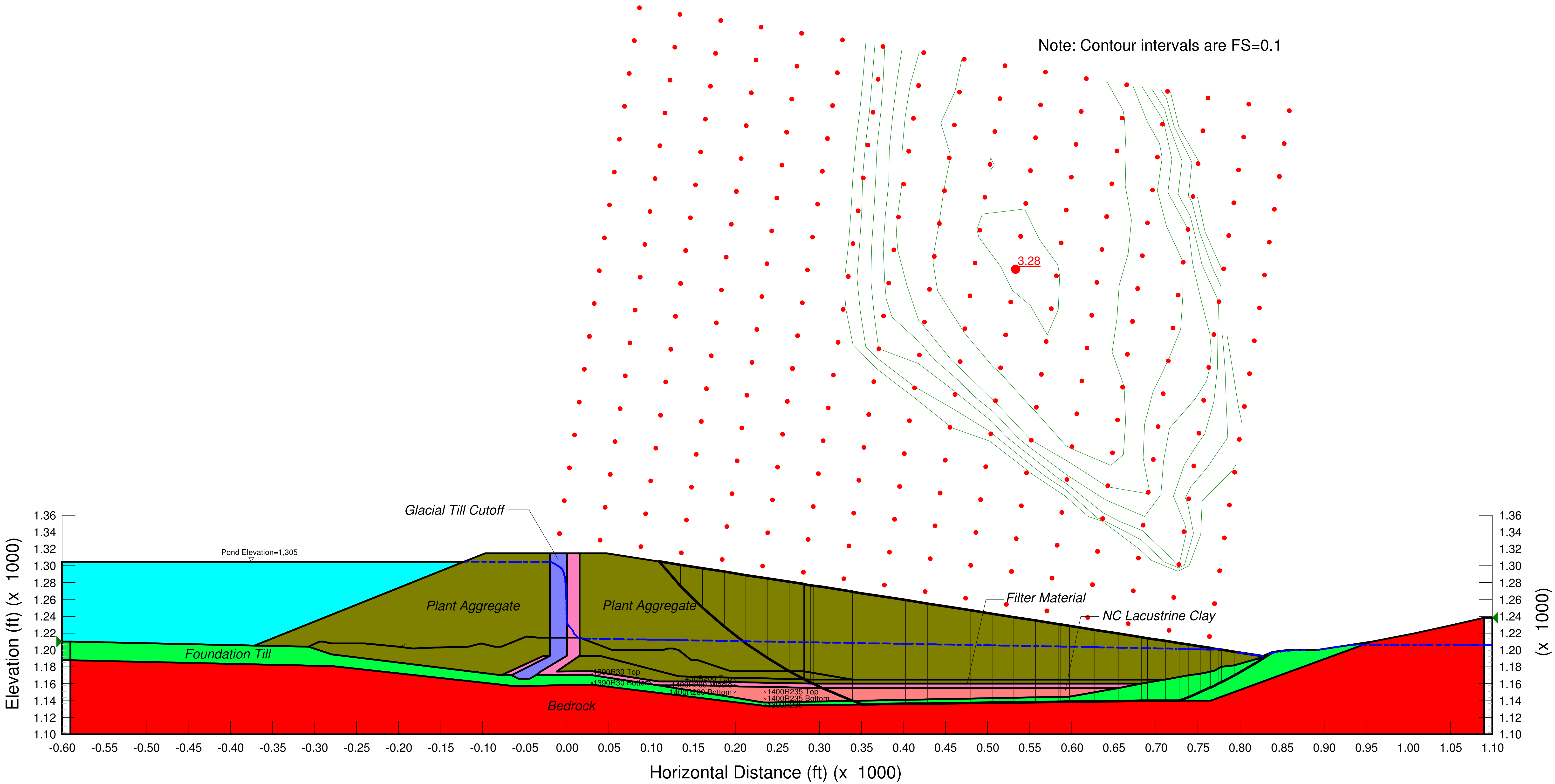
Factor of Safety: 3.28



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC DSS Average, FM Block
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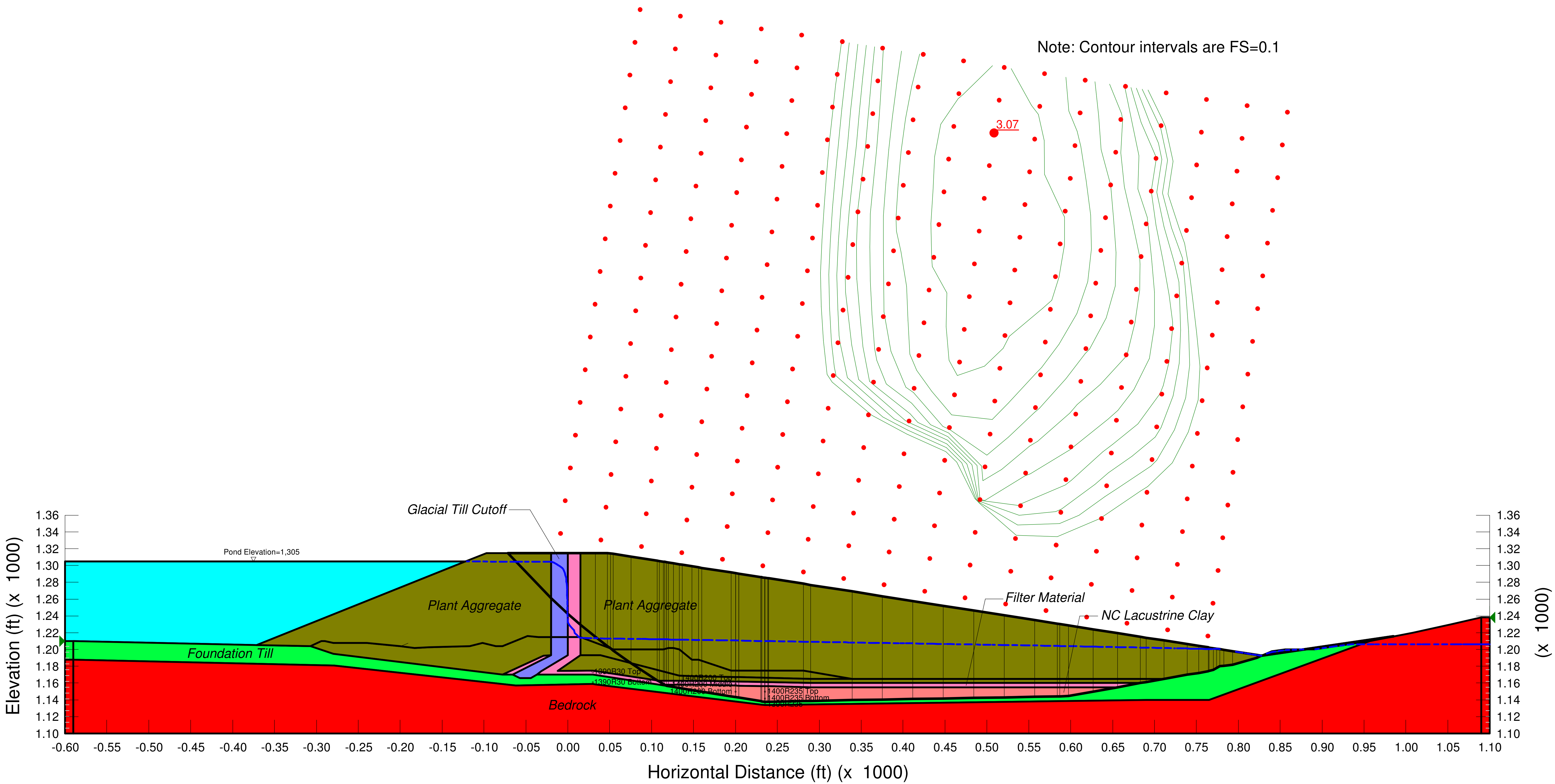

Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
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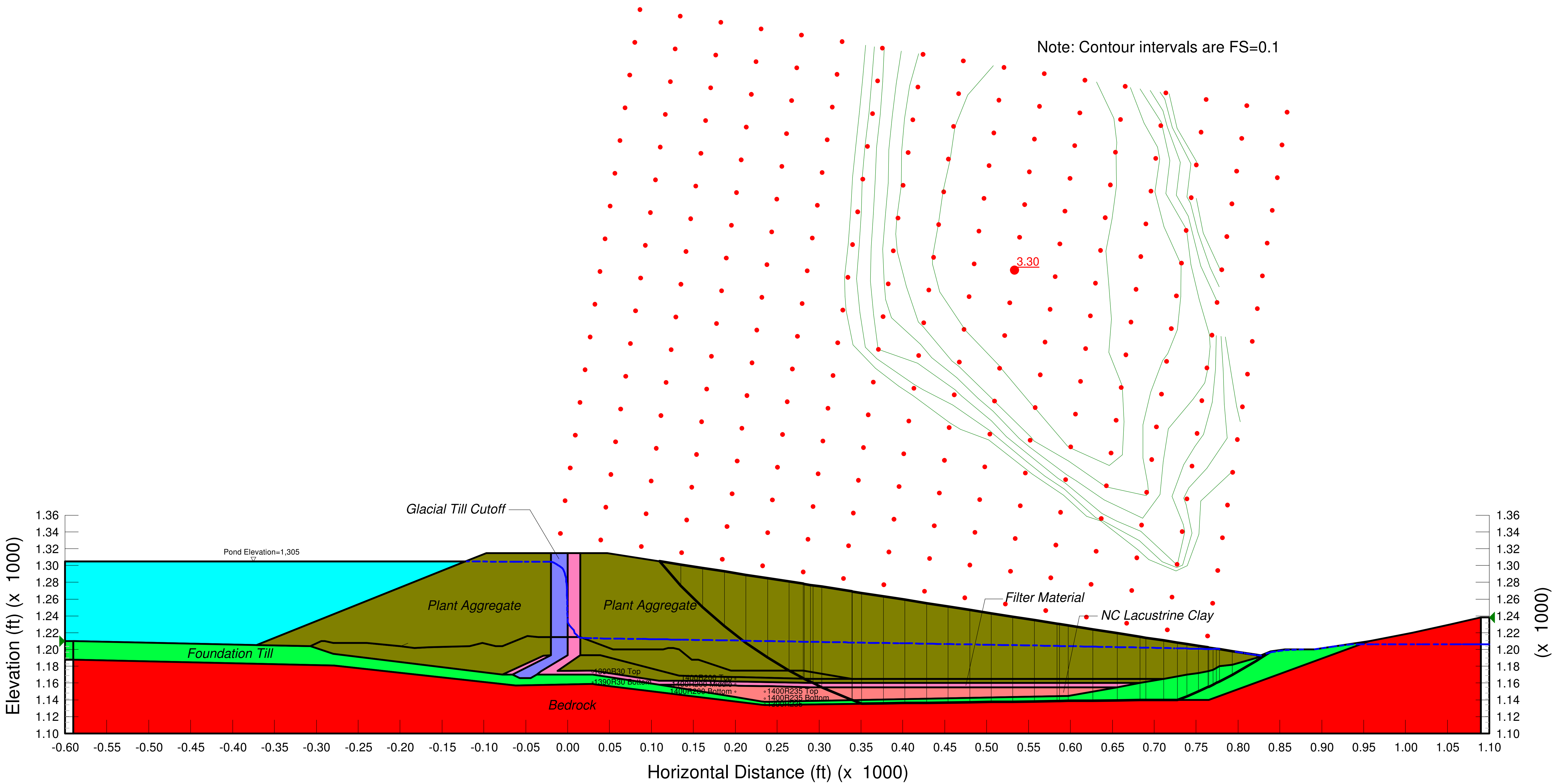
Factor of Safety: 3.30



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Low, FM Block
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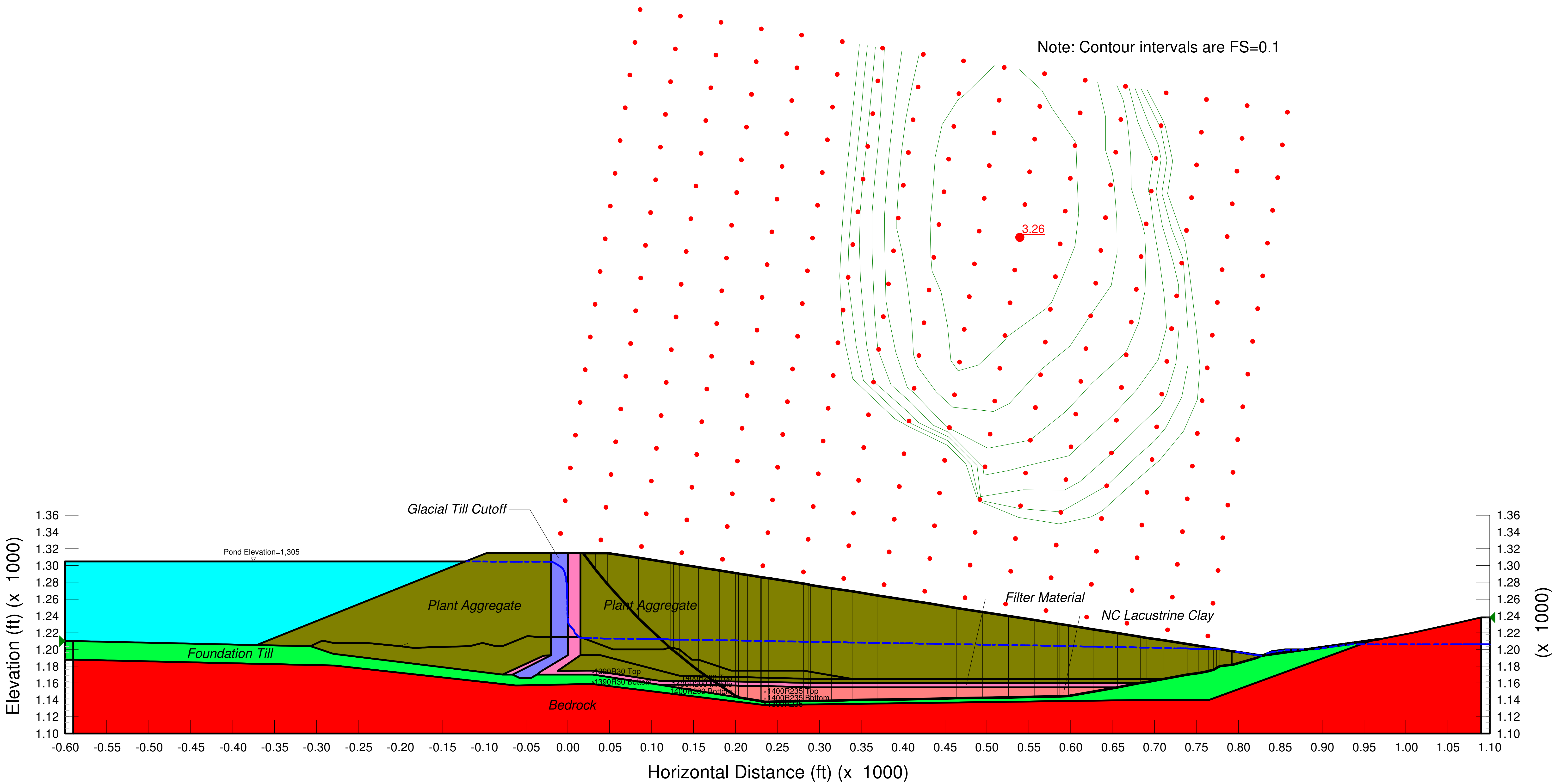

Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Toe
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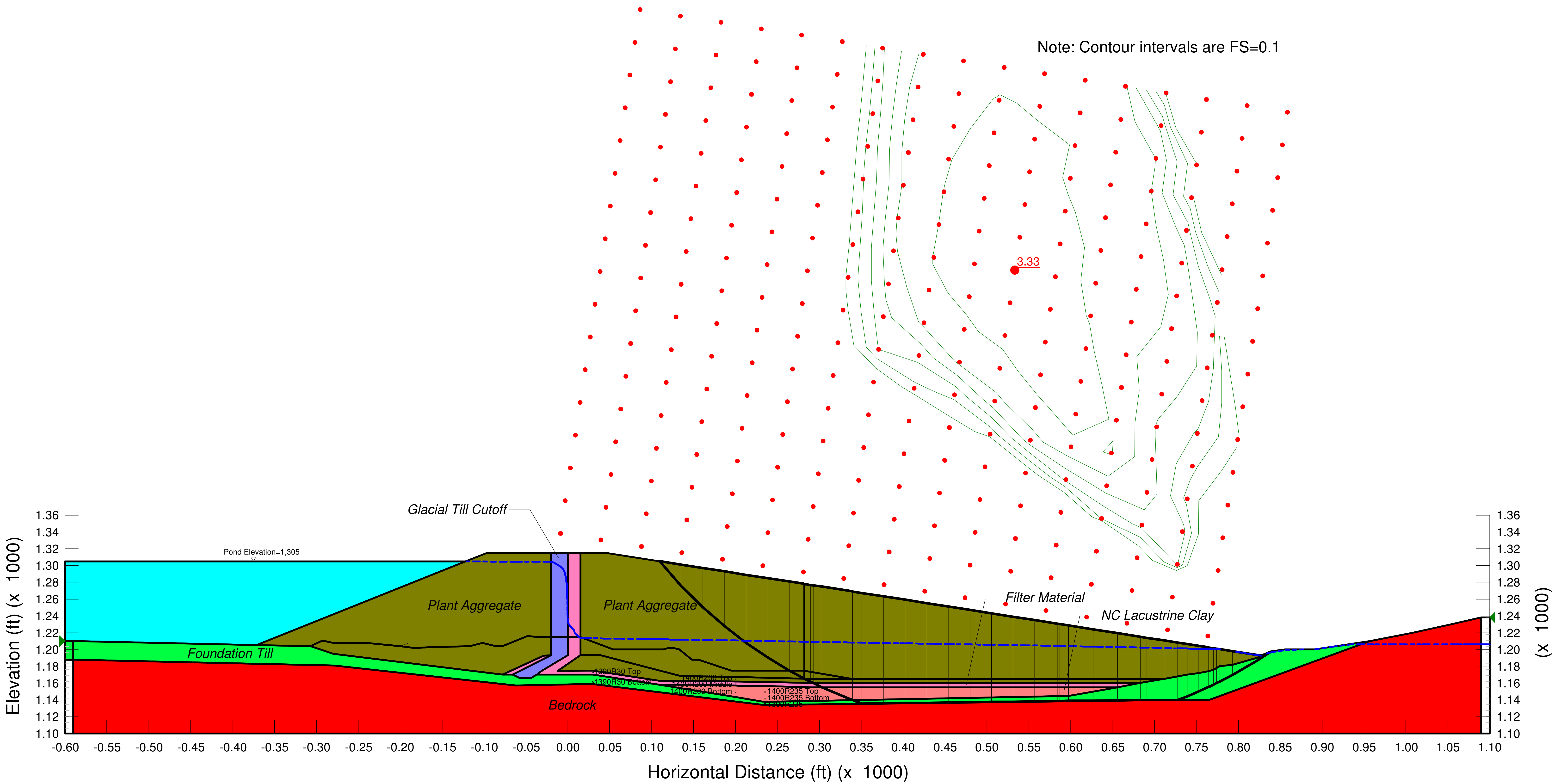
Factor of Safety: 3.33



Northshore Mining, Dam 5, Sta. 14+00, Stability Analysis
Ultimate Geometry (El. 1315), ESSA, LC TXC Average, FM Block
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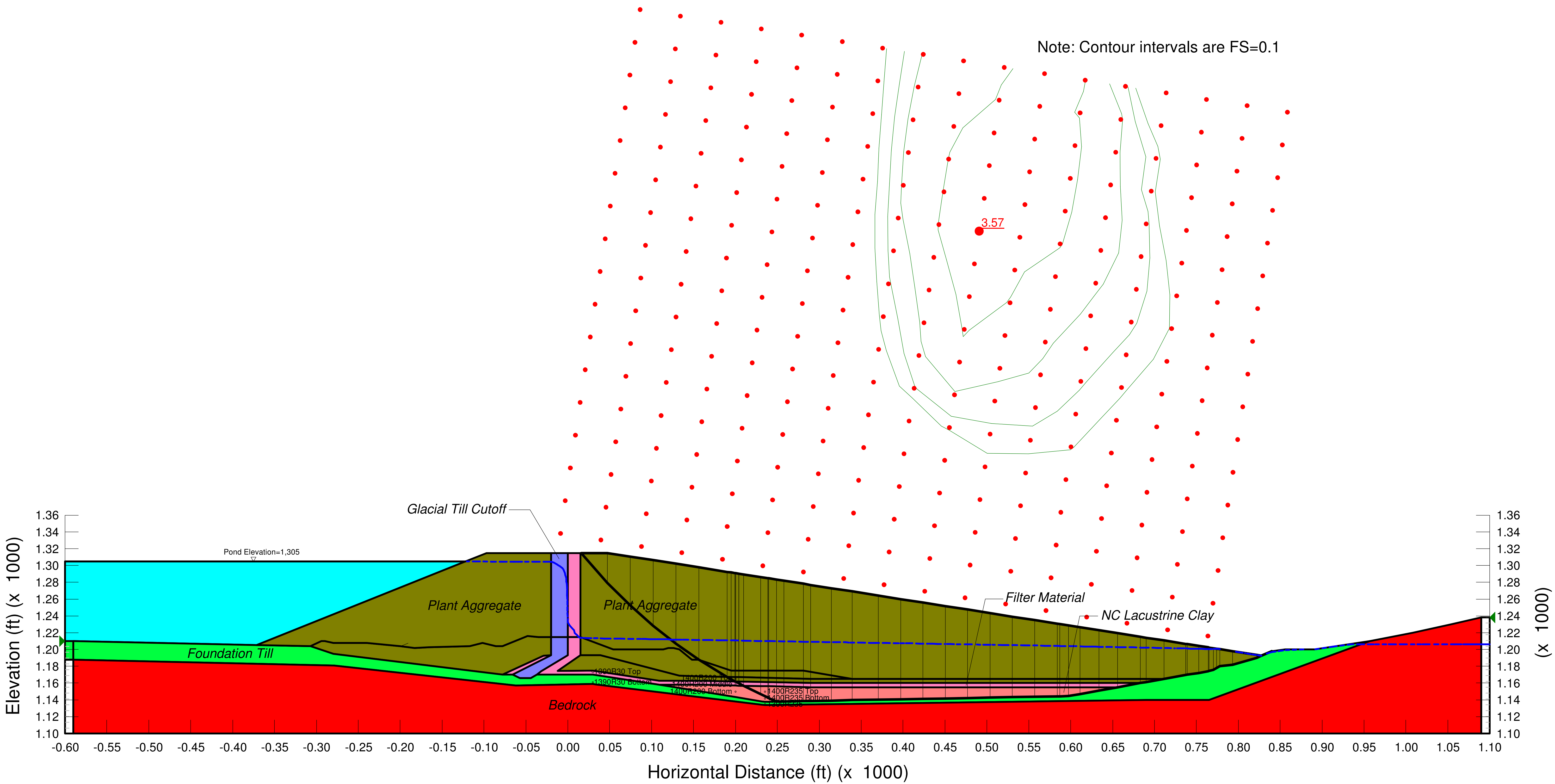
Factor of Safety: 3.57



Appendix C

Results of Slope Stability Analyses
Dam 5