Tennessee Valley Authority Kingston Fossil Plant Harriman, Roane County, Tennessee	**Perimeter Containment** **North Dredge Cell (Dike C) Segment 1** **Sta. A161+50 to A179+50**
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Exhibit 16
Reliability Analysis for Soil-Cement Strengths

Purpose:

- Deep mixing will result in variable soil-cement strengths within the constructed walls. These analyses consider how this strength variation will impact performance under design loads.

Methods:

- Conventional slope stability analyses.
- Taylor Series Method for the analysis of reliability.
- Follow general recommendations of Filz and Navin (2006).

Results:

- Results indicate how much variability (expressed as COV) in soil-cement strength can be tolerated while maintaining performance.
- Results directly incorporated into deep mixing specification, in terms of required targets for strengths of test cylinders.

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Reliability Analysis for Soil-Cement Strengths

The purpose of this reliability analysis is to determine rational targets for soil-cement (soilcrete) strengths to be measured during construction, based on stability analyses that consider variability in material strengths. The specified target strengths will recognize the expected variability in soilcrete strength, will be statistically defined, and correspond to the mean strength assumed in the design calculations.

1. Introduction

The closure plan for the failed dredge cell at the Kingston Fossil Plant will involve constructing a new perimeter berm on a stabilized foundation. Recovered ash, at controlled moisture contents, will be placed and compacted in a landfill within the new berm. Deep mixing has been selected to stabilize the perimeter berm foundation against liquefaction. Soilcrete walls with a specified, minimum thickness will be formed in a zone beneath the perimeter berm. The deep mixed walls will extend down through the foundation soils and penetrate a specified depth into bedrock. An area replacement ratio (ratio of soilcrete area to the total area in plan of the treated zone) equal to 0.26 has been specified for the first segment of construction. The design is based on an average unconfined compressive strength of f'_{sc} = 200 psi, with the shear strength equal to 40% of f'_{sc}, in the soil-cement (see Exhibit 14).

Limit equilibrium slope stability analyses and numerical modeling have been performed to support the design of the facility closure within the stabilized perimeter. The critical condition for stability is immediately after the design earthquake, when the saturated ash and alluvial foundation soils are expected to have liquefied. Slope stability analyses are based on the concept of factor of safety (*FS*), which is defined as the ratio of material shear strength to shear stress required for equilibrium along a critical, potential slip surface. A calculated factor of safety equal or greater than the target factor of safety indicates an acceptably stable slope.

The design criteria for the closure project (Exhibit 2) are expressed in terms of factors of safety for slope stability, for short-term and long-term conditions. For seismic loads, deformations within the closed landfill should not result in ash displaced past the permitted boundary. To meet this design goal, a target $FS \geq 1.1$ is desired for the post-earthquake slope stability with liquefaction (Exhibit 15).

Supplementing the conventional, factor of safety stability analyses, reliability analyses for slope stability allow for rational consideration of the uncertainties in material shear strengths. Reliability analyses yield an estimate of the probability of failure, P_f, which can be related to a reliability index for the facility performance. The expected performance of the facility in the design condition can thus be related to the distribution in measured material properties (shear strengths).

For the Kingston dredge cell closure project, reliability analyses were used to better understand how variability in soilcrete strength impacts the expected seismic performance. The reliability analyses do not replace the conventional factor of safety analyses for slope stability. Rather, the results from the reliability analyses are used to set appropriate, statistical targets for soilcrete strength in the project specifications. In addition to the requirement for a mean $f'_{sc} \geq 200$ psi, the variability in the soilcrete

strengths must be limited to achieve the desired performance. During construction, quality control tests will measure the unconfined compressive strength of soilcrete cylinders (either wet grab samples or cored specimens from deep mixed material). The analyses presented here are used to define how many of these test specimens must achieve a certain strength, consistent with the design limits for mean and variance in the strengths.

This report documents the method and results of the reliability analyses that were performed on the critical cross section (Station A168+00) identified for the first segment of the perimeter berm. Only the critical design load condition (post-earthquake with extensive soil and ash liquefaction) was subjected to the reliability analysis. Material cross section geometries are shown in the enclosed computer output plots.

2. Reliability Analysis Methodology

Reliability analysis, which has not been used in routine geotechnical practice as much as the factor of safety analysis, provides a means of distinguishing parameters with high or low uncertainties and evaluating the effects of these uncertainties on expected performance. Because deep-mixed soilcrete strengths are typically highly variable, reliability analysis can be an integral part of the engineering evaluations for a deep mixing project. Results of the reliability analysis permit material strength variability to be rationally incorporated into the design process. This facilitates the development of statistically-based specifications, which allow some soilcrete strengths to be lower than the design strength while the design intent is still fully achieved.

Four reliability analysis approaches, including the Taylor Series Method, the Point Estimate Method, the Hasofer-Lind Method, and the Direct Integration Method, are described by Filz and Navin (2006). The first three methods are approximate, simplified methods, while the Direct Integration Method is an exact method.

The Taylor Series Method was selected for the analysis reported herein. In general, the Taylor Series Method includes the following steps (Duncan and Wright 2005):

1. Estimate mean values and standard deviations (σ) of material parameters involved in the slope stability analysis.

2. Calculate the most likely value of factor of safety, F_{MLV}, using the mean values for all material parameters.

3. Calculate changes in factor of safety, $\Delta F_i = (F_i^+ - F_i^-)$, where F_i^+ and F_i^- are the calculated factors of safety with the *i-th* parameter increased and decreased by one standard deviation, respectively, from its mean value, while all the other parameters are kept at their mean values.

4. Use the Taylor series numerical method to approximate the standard deviation of the factor of safety, σ_{FS}:

$$\sigma_{FS} = \sqrt{\sum_{i=1}^{n} \left(\frac{\Delta F_i}{2} \right)^2}$$

5. Calculate the coefficient of variation of the factor of safety, COV_{FS}:

$$COV_{FS} = \frac{\sigma_{FS}}{F_{MLV}}$$

6. Calculate the reliability index of the factor of safety, β_{FS}, assuming the factor of safety is lognormally distributed:

$$\beta_{FS} = \frac{\ln \frac{F_{MLV}}{\sqrt{1 + COV_{FS}^2}}}{\sqrt{\ln\left(1 + COV_{FS}^2\right)}}$$

7. Use the "*NORMSDIST*" function in *Excel* to calculate the probability of failure, P_f, from the reliability index:

$$P_f = 1 - NORMSDIST\left(\beta_{FS}\right)$$

3. Material Properties

The critical design condition for stability is a post-earthquake condition, where saturated ash and foundation soils are expected to have liquefied. This condition was assumed in the analysis here, with post-earthquake, undrained or liquefied strengths assumed for each material as appropriate.

Materials involved in the analyzed cross section included (1) landfilled ash, (2) hydraulically placed ash, (3) lean clay foundation soil, (4) sandy silt to silty sand, (5) soilcrete walls from deep mixing, (6) earthen berm, (7) coarse stone, (8) shot rock, and (9) shale bedrock. Based on the critical slip surfaces identified in the conventional limit equilibrium stability analyses (Exhibit 15), the stability of the slope will be mainly affected by the strengths of the first five materials, while the strengths of the other four materials would not have a significant effect on the probability of failure. Therefore, in the reliability analyses, only the first five materials' strengths were varied. Strength parameters of the other four materials, as well as the unit weights of all soils, were taken at their mean values.

Material properties used in the reliability analyses of post-earthquake slope stability are summarized in Table 1. These parameters were estimated either from tests performed for the project or, when testing data were unavailable or inadequate, from published references. The following paragraphs briefly describe how the strength parameters of the first five materials were determined. The referenced laboratory test data on the Kingston soils are provided in Exhibit 13.

3.1. Landfilled Ash

Three consolidated-undrained (CU) triaxial tests with pore water pressure measurements were performed on recovered ash material compacted at 90 percent of its standard Proctor maximum dry density, resulting in drained strength of $\phi' = 38^o$, $c' = 0$ and static undrained strength of $\phi = 27^o$, $c = 1{,}200$ psf.

However, our experience with similar ash materials at other sites indicated a much lower drained friction angle. Considering the ash material type (ML) and the anticipated density of the landfilled ash, along with the correlations presented in NAVFAC (1986), drained strengths of $\phi' = 30^o$ and c' = 0 were selected for the landfilled ash.

For the above selected drained strengths ($\phi' = 30^o$, c' = 0) and undrained strengths ($\phi = 27^o$, c = 1,200 psf), the undrained strength envelope is above the drained strength envelope when normal stress levels are less than 17,690 psf. The higher undrained strength is due to negative pore pressures generated by shearing, which may not be sustainable. To avoid a reliance on these negative pore pressures for increased shearing resistance, the smaller of the drained and undrained strengths should be used in undrained analyses. In the normal stress regime associated with the height of the proposed landfill ash embankment, the drained strength is always smaller than the undrained strength; thus, $\phi' = 30^o$ and c' = 0 were selected to represent the landfilled ash in an undrained analysis.

For saturated soils that do not liquefy during a seismic event, 80 percent of the static undrained strength is typically used in the post-earthquake stability analyses to account for excess pore water pressures generated due to the seismic loading. However, since the landfilled ash will be mechanically compacted under controlled conditions, and the majority of the compacted ash will be above the groundwater level, its full static undrained strength was used in the analyses presented here.

Due to insufficient testing data, the coefficient of variation (*COV* = 10%) of the landfilled ash strength was selected based on USACE (2006).

3.2. Hydraulically Placed Ash

Results from liquefaction triggering analyses, performed using the available SPT and CPT data, indicated that the hydraulically placed ash would liquefy during the design earthquakes (Exhibit 11). Thus, the residual strength of this material was used in the post-earthquake stability analyses.

Correlations between residual strength ratio (S_{us}/σ_v') and SPT and CPT data developed by Olson and Stark (2002) and Idriss and Boulanger (2007) were used to estimate the residual strength of the hydraulically placed ash material. The mean value of the calculated residual strength ratios was 0.06.

Since sufficient SPT and CPT data were available for the hydraulically placed ash, two methods were used to estimate the *COV* of the residual strength ratio. One was a statistical method and the other one was the "3-σ Rule" (Duncan and Wright, 2005).

Using the statistical method, the standard deviation and coefficient of variation can be calculated from the following formulas:

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - x_{mean})^2}$$

$$COV = \frac{\sigma}{x_{mean}}$$

Where σ is the standard deviation, N is the number of measurements, x is the measured data, and x_{mean} is the mean value of the measured data.

The "3-σ Rule" is based on 99.73% of all values of a normally distributed parameter falling within plus or minus three standard deviations of the mean. Therefore, if *HCV* and *LCV* are the highest and lowest conceivable values of the parameter, respectively, then *HCV* is about three standard deviations above the mean and *LCV* is about three standard deviations below the mean. The standard deviation is thus equal to the difference between *HCV* and *LCV* divided by 6.

$$\sigma = \frac{HCV - LCV}{6}$$

Previous studies have shown that there is a tendency to underestimate standard deviations (Christian and Baecher, 2001). Duncan and Wright (2005) suggested that if the sample sizes were in the range of 20 to 30 values, a better estimate of standard deviation would be made by dividing the difference between *HCV* and *LCV* by 4 instead of 6. This is referred to as the "2-σ Rule" in this report.

$$\sigma = \frac{HCV - LCV}{4}$$

For the residual strength ratio of the hydraulically placed ash material, the values of *COV* were estimated at 31 percent based on the statistical method and 50 percent based on the "3-σ Rule". The more conservative *COV* value of 50 percent from the "3-σ Rule" was selected for the analyses presented in this report. This seemingly large *COV* is consistent with the substantial uncertainty in available correlations for residual (liquefied) strength ratio.

Landfilled ash in capillary fringe, in a zone of up to eight feet above the phreatic surface, is also susceptible to liquefaction (Exhibit 12). The residual strength ratio and *COV* of the liquefied landfilled ash were assumed to be the same as those of the hydraulically placed ash.

3.3. Lean Clay Foundation Soil

A total of 34 CU triaxial compression tests were performed on the alluvial lean clay soil. The measured static undrained strength parameters were: mean-ϕ = 33°, HCV-ϕ = 60°, LCV-ϕ = 15°, and no cohesion. The lean clay soil is located below the groundwater table and will not liquefy during the design earthquakes. The post-earthquake undrained strength was taken at 80% of the static

undrained strength, resulting in mean-ϕ = 28°, HCV-ϕ = 54°, LCV-ϕ = 12°, and no cohesion.

The *COV* value of the post-earthquake undrained friction angle was estimated at 42% based on the statistical method. The "2-σ Rule" resulted in a *COV* value of 37%. For this analysis, the selected value of *COV* was 40%. This is consistent with the typical value recommended by Harr (1987) for undrained shear strengths.

3.4. Sandy Silt to Silty Sand

Results from liquefaction triggering analyses indicated that the sandy silt to silty sand alluvial material would liquefy during the design earthquakes. Its mean strength parameters and the *COV* were estimated using the same approaches as those for the hydraulically placed ash. The calculated mean residual strength ratio was 0.06. The calculated *COV* values were 34% based on the statistical method and 49% based on the "3-σ Rule", and the *COV* selected for this study was 50%.

3.5. Soilcrete Wall

The project design assumes a mean, unconfined compressive strength of f'_{sc} = 200 psi for the deep mixed, soilcrete walls. As discussed in Exhibit 14, the shear resistance is taken at 40% of the unconfined compressive strength, or c = 0.4 (200 psi) = 80 psi = 11,520 psf, with ϕ = 0.

The unconfined compressive strength of the soilcrete is influenced by many factors, such as in-situ soil type, binder materials, mix design, installation process, curing conditions, etc. As a result, soilcrete strength can be highly variable. Filz and Navin (2006) recommend *COV* values for soilcrete strength ranging from 40 to 70 percent should be used in a reliability analysis. In this report, a wider *COV* range (20 to 70 percent) was considered.

Filz and Navin (2006) analyzed a total of 7,000 unconfined compressive strength data for deep mixed materials from nine project sites in the U.S. It was shown that the lognormal distribution provides the best fit to the data sets. A comparison of the fit of four standard distributions (lognormal, normal, triangle, and uniform) to the strength data from one site is shown in Figure 1.

In the reliability analysis described in this report, the lognormal distribution was assumed for the soilcrete strength. Strengths of the other four materials discussed above were assumed to have normal distributions.

The approaches used to obtain the remainder of the parameters presented in Table 1 are detailed in Exhibit 13. Composite strength parameters within the stabilized footprint were calculated based on the area replacement ratio method (Exhibit 14). A weighted average was computed from the strengths of the soilcrete and untreated materials, with different composite strengths computed for each ash or soil layer in the foundation. The current design is using an area replacement ratio of 0.26. Composite strengths can then

be calculated based on this area replacement ratio and the strength parameters listed in Table 1.

Within the reliability analyses, the *COV* for the composite strength of each stabilized soil zone was not explicitly estimated. Instead, the variability in strength for the soilcrete and the untreated soil were considered independently, and the corresponding composite strength was carried forward in the stability analyses. For example, when considering the *HCV* for the soilcrete strength, the mean strength of the untreated soil and the *HCV* for the soilcrete were used to compute the composite strength that was then used in the stability calculation.

Table 1 – Material Parameters used in Reliability Analysis

Material Name	Unit Weight, (pcf)		Undrained, Total Stress Strength Parameters for Post-Earthquake Conditions				Source of Coefficient of Variation
			Mean Value			Coefficient of Variation, *COV*	
	γ_m	γ_{sat}	ϕ, (deg.)	c, (psf)	S_{us}/σ_v'		
Landfilled Ash	109	111	30	0	--	10%	USACE, 2006
Hydraulically Placed Ash	100	107	--	--	0.06	50%	SPT and CPT data
Lean Clay Foundation Soil	--	130	28	0	--	40%	CU test data
Sandy Silt to Silty Sand	--	128	--	--	0.06	50%	SPT and CPT data
Soilcrete Wall*	Same as untreated soils		0	11,520	--	20 to 70%	Filz and Navin, 2006
Earthen Berm	125	128	0	1,500	--	--	--
Coarse Stone	115	128	32	0	--	--	--
Shot Rock	115	128	38	0	--	--	--
Shale	--	140	20	3,000	--	--	--

* Average shear strength of soilcrete = 0.4 f'_{sc} = 0.4 (200 psi) = 11,520 psf. Composite strengths for the stabilized foundation layers were computed for an area replacement ratio = 0.26.

4. Reliability Analyses of Slope Stability

Two-dimensional, limit equilibrium stability analyses were performed on the previously defined, critical cross section (at Sta. A168+00) for the post-earthquake conditions. The analyses were carried out using the computer program SLOPE/W and the methods described in Exhibit 15. A total of 11 cases were analyzed; the output plots are presented in Appendix A.

For each case, two failure modes were evaluated. One was a slip surface cutting through the treated foundation near the top of rock (deep failure), and the other was a slip surface in the side slope of the landfilled ash embankment that exited behind the perimeter berm (shallow failure). Table 2 presents the strength parameters used in each case along with the computed factors of safety. It was noted that with the selected mean soilcrete strength (c = 80 psi) and *COV* range (20 – 70 %), the majority of the slip surfaces in the side slope did not pass through the inboard corner at the top of the stabilized footprint; thus, the calculated factors of safety associated with the shallow failure mode were not affected by the *COV* of the soilcrete strength. Consequently, only the deep failure mode was considered in computing the reliability index and the probability of failure using the Taylor Series Method. The results are presented in Table 3.

Table 2 – Summary of Limit Equilibrium Stability Analyses

Case Name	Material Strengths [1]					Calculated Factors of Safety	
	Landfilled Ash	Hydraulically Placed Ash	Lean Clay Foundation Soil	Sandy Silt to Silty Sand	Soilcrete Panel	Slip Surface Through Treated Foundation	Slip Surface Out at Landfill Side slope
Case 1	mean	mean	mean	mean	mean	2.10 [2]	1.55 [2]
Case 2	mean - σ	mean	mean	mean	mean	2.09	1.49
Case 3	mean + σ	mean	mean	mean	mean	2.11	1.61
Case 4	mean	mean – σ	mean	mean	mean	2.07	1.20
Case 5	mean	mean + σ	mean	mean	mean	2.15	1.85
Case 6	mean	mean	mean – σ	mean	mean	1.99	1.55
Case 7	mean	mean	mean + σ	mean	mean	2.20	1.55
Case 8	mean	mean	mean	mean – σ	mean	2.00	1.55
Case 9	mean	mean	mean	mean + σ	mean	2.21	1.55
Case 10	mean	mean	mean	mean	mean – σ	1.79 (*COV* [3] = 20%)	1.54 (*COV* [3] = 20%)
						1.63 (*COV* [3] = 30%)	1.54 (*COV* [3] = 30%)
						1.48 (*COV* [3] = 40%)	1.54 (*COV* [3] = 40%)
						1.32 (*COV* [3] = 50%)	1.53 (*COV* [3] = 50%)
						1.17 (*COV* [3] = 60%	1.54 (*COV* [3] = 60%)
						1.01 (*COV* [3] = 70%)	1.49 (*COV* [3] = 70%)
Case 11	mean	Mean	mean	mean	mean + σ	2.39 (*COV* [3] = 20%)	1.55 (*COV* [3] = 20%)
						2.55 (*COV* [3] = 30%)	1.55 (*COV* [3] = 30%)
						2.64 (*COV* [3] = 40%)	1.55 (*COV* [3] = 40%)
						2.75 (*COV* [3] = 50%)	1.55 (*COV* [3] = 50%)
						2.78 (*COV* [3] = 60%)	1.55 (*COV* [3] = 60%)
						2.78 (*COV* [3] = 70%)	1.55 (*COV* [3] = 70%)

Note: 1 – In all 11 cases, mean strengths were used for the other three materials (earthen berm, coarse stone, shot rock, and shale bedrock).
2 – Most likely value of factor of safety, F_{MLV}.
3 – *COV* of soilcrete strength.

Table 3 – Summary of Reliability Analyses for Slope Stability

Soilcrete COV	F_{MLV}	σ_{FS}	COV_{FS}	β_{FS}	P_f
20%	2.10	0.34	16%	4.57	0.000002
30%	2.10	0.49	23%	3.14	0.0008
40%	2.10	0.60	29%	2.51	0.006
50%	2.10	0.73	35%	2.02	0.022
60%	2.10	0.82	39%	1.78	0.037
70%	2.10	0.90	43%	1.60	0.054

5. Design Guidance

Guidance for selecting an appropriate probability of failure (P_f) is provided in ETL 1110-2-547 (USACE 1995). These guidelines are presented here in Table 4.

Although the condition analyzed in this report was one of the worst case scenarios (post-earthquake with liquefied soils), considering the significance of the project, above average performance (reliability index of 3.0 and a probability of failure of 0.001) was selected as the target reliability level. Comparing this target level with the results presented in Table 3, a coefficient of variation of soilcrete strength of about 30 percent could be used to develop statistically-based specifications with the mean design unconfined compressive strength of 200 psi. That is, a mean f'_{sc} = 200 psi and $COV \leq$ 30% will result in a $P_f < 0.001$ and above average performance.

Table 4 – Target Reliability Levels

Expected Performance Level	β_{FS}	P_f
High	5.0	0.0000003
Good	4.0	0.00003
Above Average	3.0	0.001
Below Average	2.5	0.006
Poor	2.0	0.023
Unsatisfactory	1.5	0.07
Hazardous	1.0	0.16

6. Statistically-Based Soilcrete Strengths

6.1. Sampling and Test Frequency

Filz and Navin (2006) recommended two approaches for determining sampling/testing frequency: daily production approach and parcel approach. In the daily production approach, one soilcrete element from the deep mixed columns produced each day by each rig is randomly selected by the engineer for coring. Specimens selected for

unconfined compressive strength tests are roughly one specimen for every five feet of soilcrete length. In the parcel approach, the project site is divided into square parcels with a parcel size ranging from about 1,500 to 4,000 square feet, depending on subsurface soil conditions. Within each parcel, three soilcrete elements are randomly selected by the engineer for coring and testing at 28 days after installation. Again, unconfined compressive strength tests are performed on specimens taken at a frequency of about one specimen for every five feet of soilcrete length.

The parcel approach will be used for Quality Control in the Kingston project, with testing frequencies appropriate for the substantial length of deep mixed walls to be constructed. A "test parcel" will be defined as a continuous, 100-foot length of soil-cement wall (a test parcel may include parts of shear walls and perimeter walls). Within each segment of the completed perimeter, at least 20% of the total length of constructed walls will be designated as test parcels. Then, in each test parcel, at least three core holes will be advanced and at least 25 specimens will be selected for strength testing.

One shear/buttress will be 100 feet long in the first design segment; considering the length of the connecting perimeter walls, a test parcel will then correspond to about every fourth shear wall. The spacing of the adjacent shear walls will be 14 to 20 feet (for 3-ft to 4-ft thick walls), such that the distance between the adjacent test parcels will be 42 to 60 feet. This is consistent with the range of autocorrelation distances (40 to 60 feet) mentioned by Filz and Navin (2006).

Assuming a daily production rate of about 750 cubic yards of production per rig, about 100 ft of 4-ft thick wall can be built in a day (assumes an average depth of 50 ft). A deep mixing rig that could build a 3-ft thick wall at about 500 cubic yards per day could construct about 90 ft of wall to a depth of 50 ft. In either case, it would take 5 to 6 days for one mixing rig to construct 500 linear feet of wall, with one 100-ft test parcel (20% of the completed wall). Hence, based on these assumed production rates, there will be about one test parcel (and three core holes) for each week of work by one mixing rig. The actual frequency of test parcels and core holes will depend on the production rate achieved by the contractor.

6.2. Distribution of Strengths

Filz and Navin (2006) also recommended that soilcrete specifications be written to require that the test results meet or exceed three levels of strengths: 60, 80, and 95 percent. That is, 60 percent of the specimens tested must meet or exceed some specified strength level, 80 percent of the specimens tested must meet or exceed a lower specified strength, and 95 percent (essentially all) specimens tested must meet or exceed some minimal specified strength. Somewhat different limits were selected for this project, as described below.

The lognormal distribution was used to generate the plot in Figure 2, which can be used to select target strength levels based on the mean and coefficient of variation. For *COV* = 30%, the 50, 75, and 95 percent exceedance values are equal to 96, 79, and 59 percent of the mean value, respectively. Thus, for a mean soilcrete strength of f'_{sc} = 200 psi, the 50, 75, and 95 percent exceedance values for strength are 192, 158, and 118 psi, respectively. Rounding up, limits for the specifications were selected at strengths of 200, 165, and 130 psi.

These limits may be understood more clearly by considering the plot in Figure 3. Here, a cumulative distribution curve is plotted for a lognormal distribution having a mean of f'_{sc} = 200 psi and a *COV* of 30%. The target exceedance strengths (50% greater than 200 psi, 75% greater than 165 psi, and 95% greater than 130 psi) are also plotted for comparison. Each of the selected target values are slightly greater than the distribution curve determined in the reliability analysis above.

Further consideration of the plot in Figure 3 suggests that the 95% strength limit should not be treated as a 100% limit. That is, a requirement that 100% of the samples have a measured strength greater than 130 psi would be overly restrictive in the tail end of the distribution. To allow the specifications to more closely follow the required distribution, a 100% exceedance value of 100 psi was thus selected.

The specified median strength of 200 psi corresponds directly with the mean strength assumed in the design. The other limiting strengths represent how much variability in soilcrete strength can be tolerated in the final construction, and corresponds to *COV* = 30%. Filz and Navin (2006) examined the published literature on deep mixed soils and found that the coefficient of variation for strength in these materials generally ranges from about 15% to 75%. Hence, *COV* = 30% would represent fairly good, but attainable uniformity (relatively low variability) in typical deep mixing operations. A contractor that cannot achieve this low variability can still meet the requirements of the specification by producing a higher cement content material with a higher mean strength. At the same time, a contractor who can achieve the lower target variability (*COV* = 30%) would have a commercial advantage in that the specification could be achieved with less cement and a mean strength closer to 200 psi.

7. Soilcrete Strength Specifications

For Quality Control in the Kingston project, soilcrete samples will be acquired from core holes in defined test parcels:

- A “test parcel” is defined as a continuous, 100-foot length of soil-cement wall.
- Within each segment of the completed perimeter, at least 20% of the total length of constructed walls will be designated as test parcels.
- At least three core holes will be advanced in each test parcel.
- From the cores, at least 25 specimens will be selected for strength testing.

Based on these analyses and considerations, the specifications for the strength of the soilcrete samples from each test parcel will be written as follows:

- 50 percent of the tested soilcrete specimens must have an unconfined compressive strength of 200 psi or greater
- 75 percent of the tested soilcrete specimens must have an unconfined compressive strength of 165 psi or greater

- 95 percent of the tested soilcrete specimens must have an unconfined compressive strength of 130 psi or greater

- 100 percent of the tested soilcrete specimens must have an unconfined compressive strength of 100 psi or greater

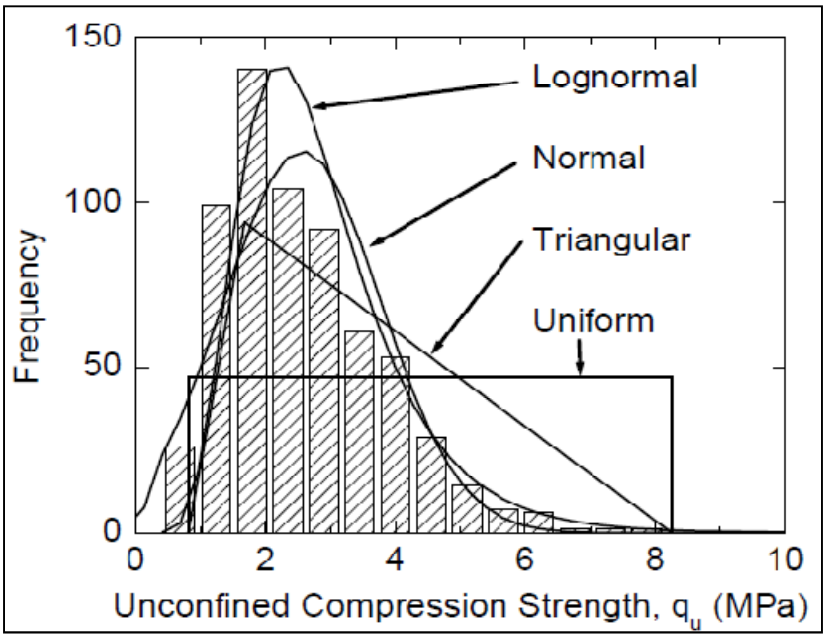

Figure 1 – Comparison of Fits between Four Probability Distributions and Measured Soilcrete Strengths (from Filz and Navin, 2006)

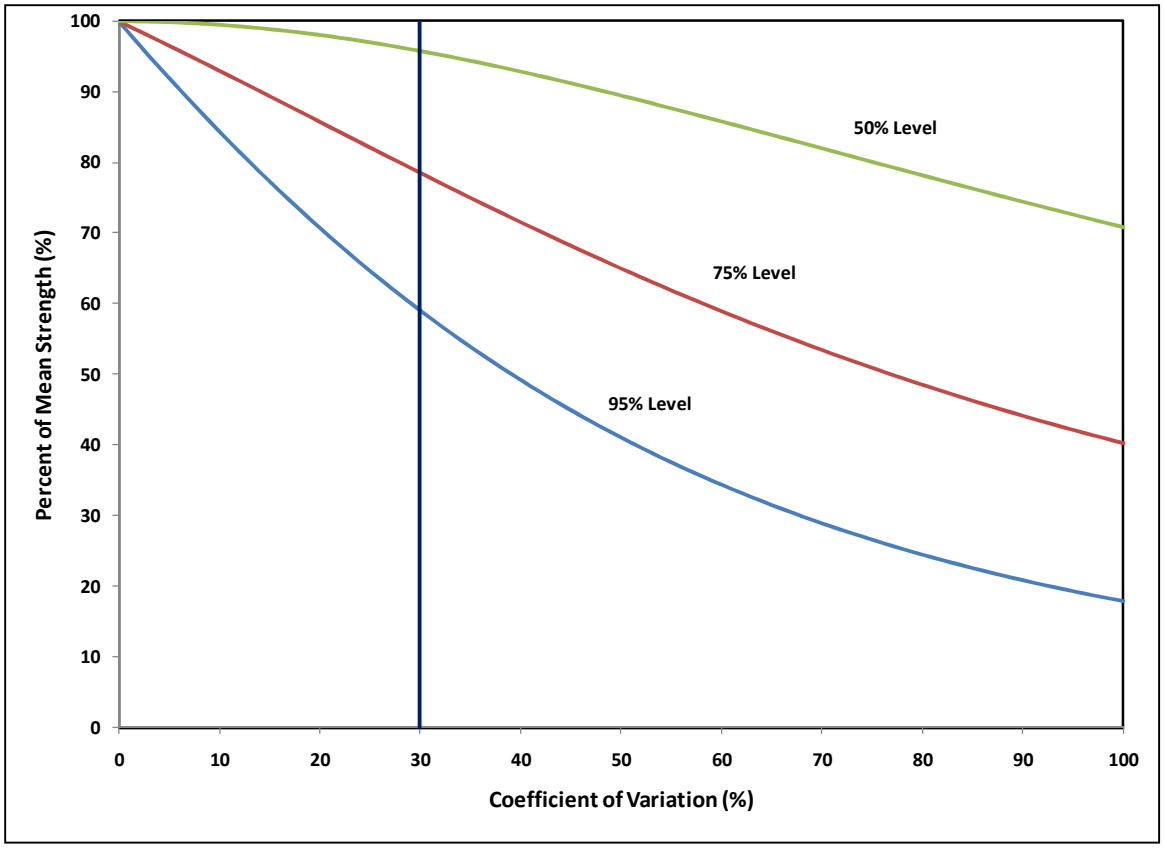

Figure 2 – 50%, 75%, and 95% Strengths from the Lognormal Distribution of Material Strengths

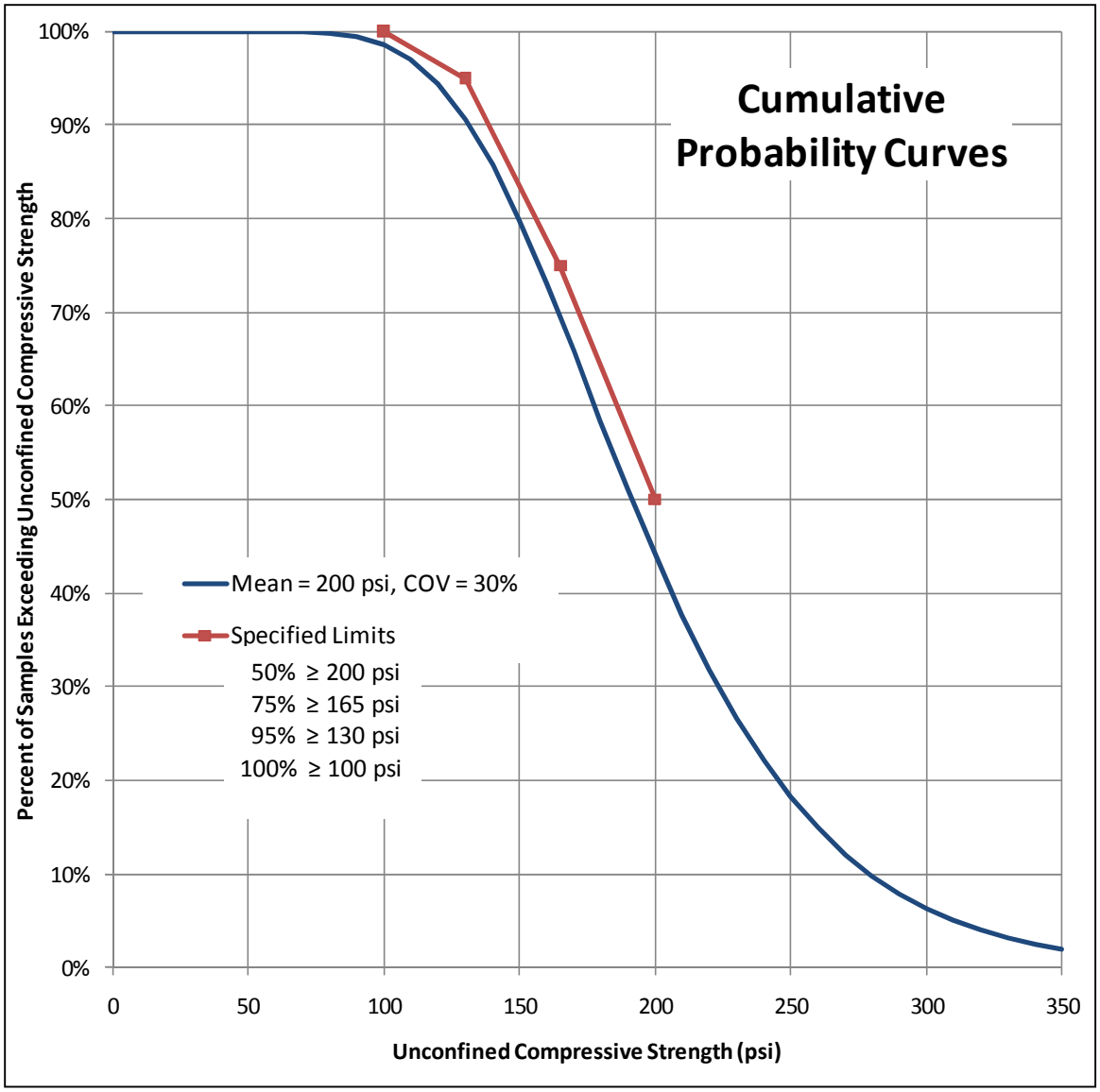

Figure 3 – Specified Limits for Soil-Cement Strength Compared to Cumulative Probability Distribution Indicated by Reliability Analysis

1. References

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Appendix A

Slope Stability Analyses used in the Reliability Analysis

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.10
Center = (25.023, 1222.56)
Radius = 162.739

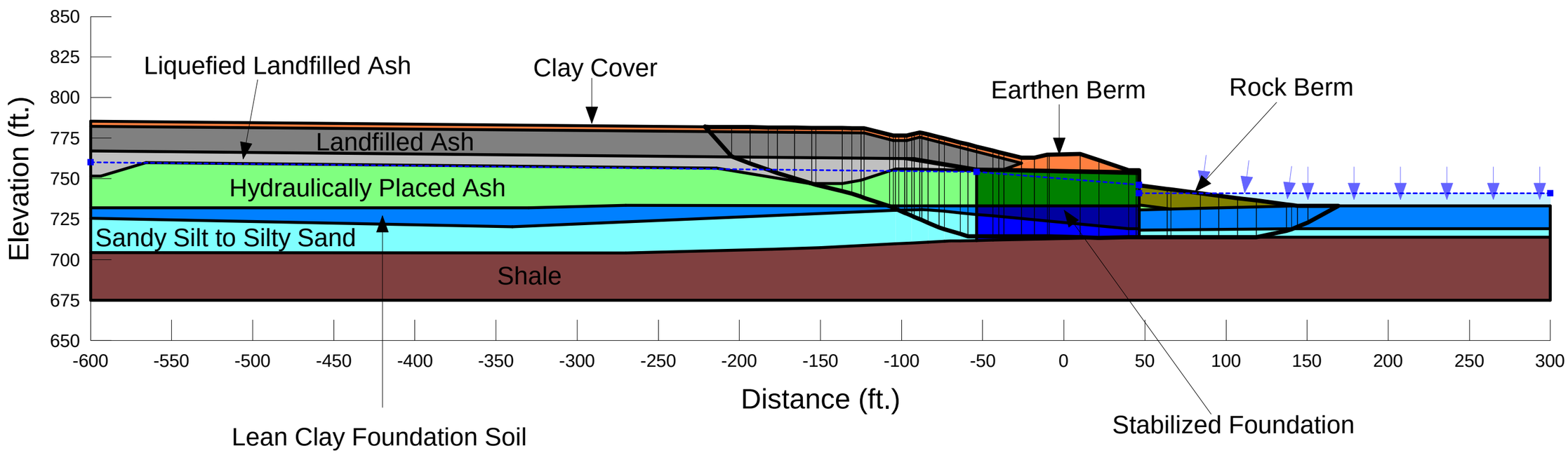

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Figure 1.A -- Case 1, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

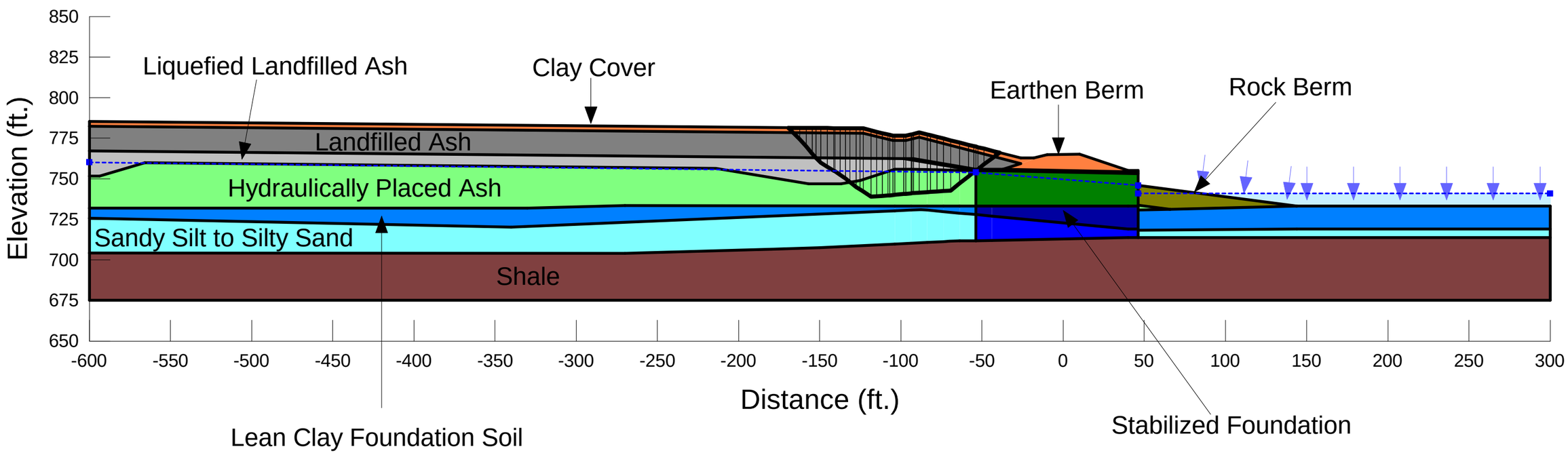

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Figure 1.B -- Case 1, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=27
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.09
Center = (25.023, 1222.56)
Radius = 160.8871

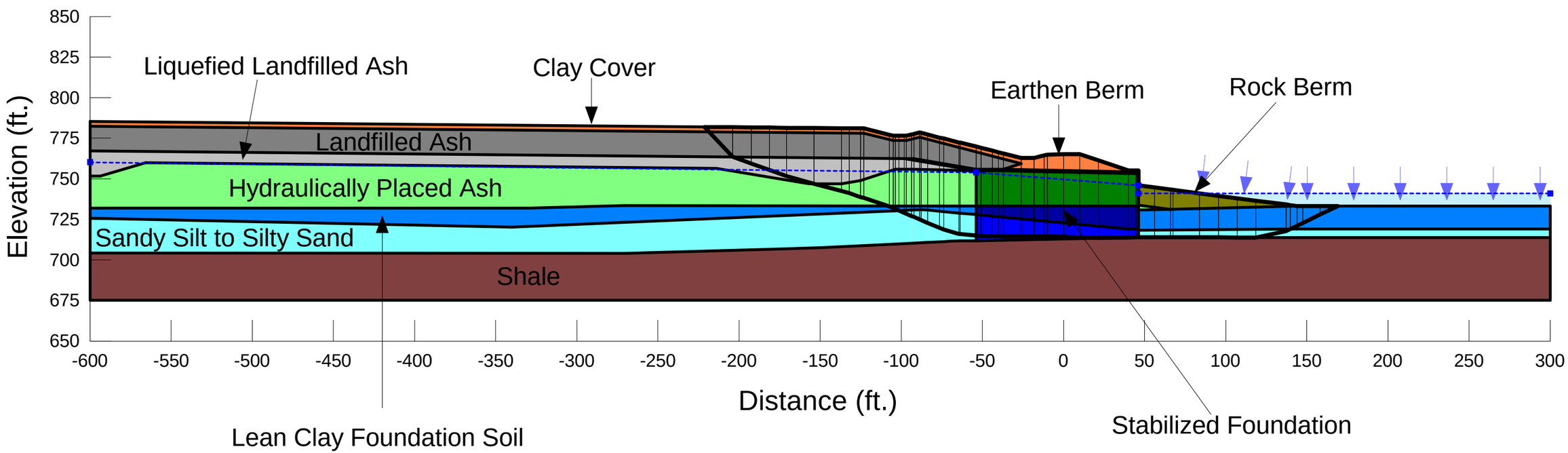

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Figure 2.A -- Case 2, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=27
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.49
Center = (-101.687, 825.088)
Radius = 60.00327

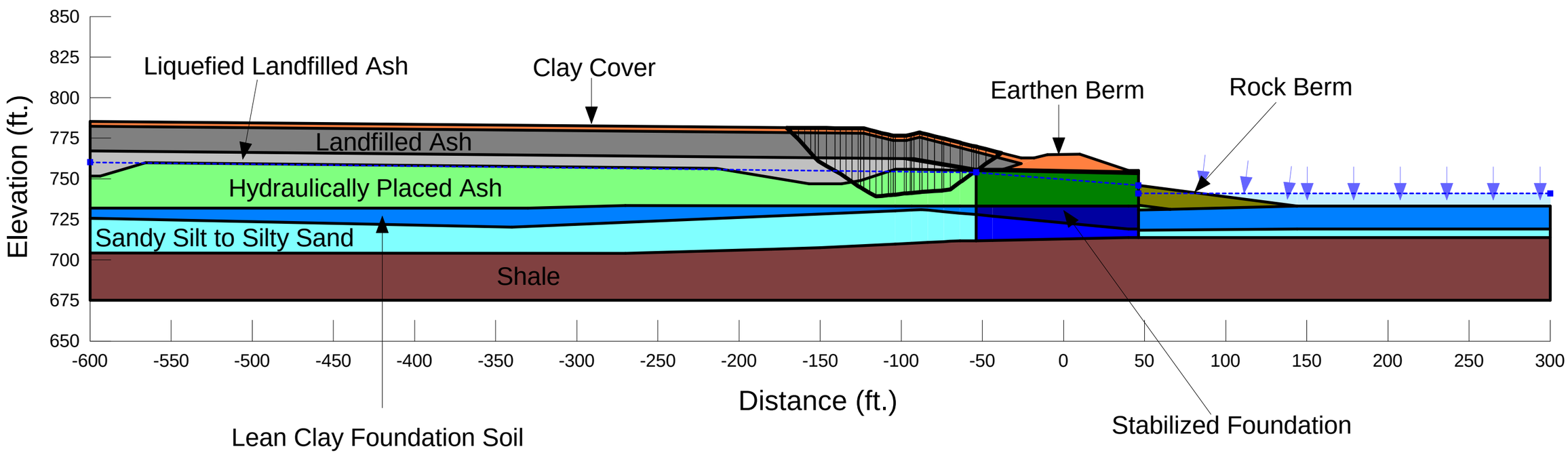

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Figure 2.B -- Case 2, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=33
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.11
Center = (25.023, 1222.56)
Radius = 163.0326

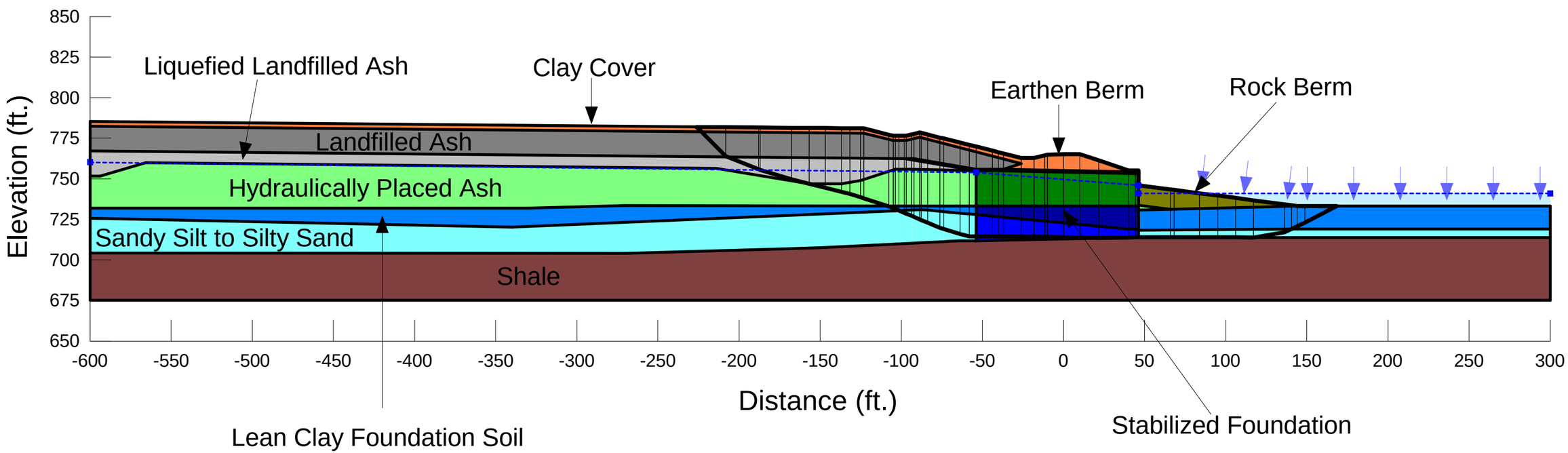

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Figure 3.A -- Case 3, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=33
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.61
Center = (-101.687, 825.088)
Radius = 60.01931

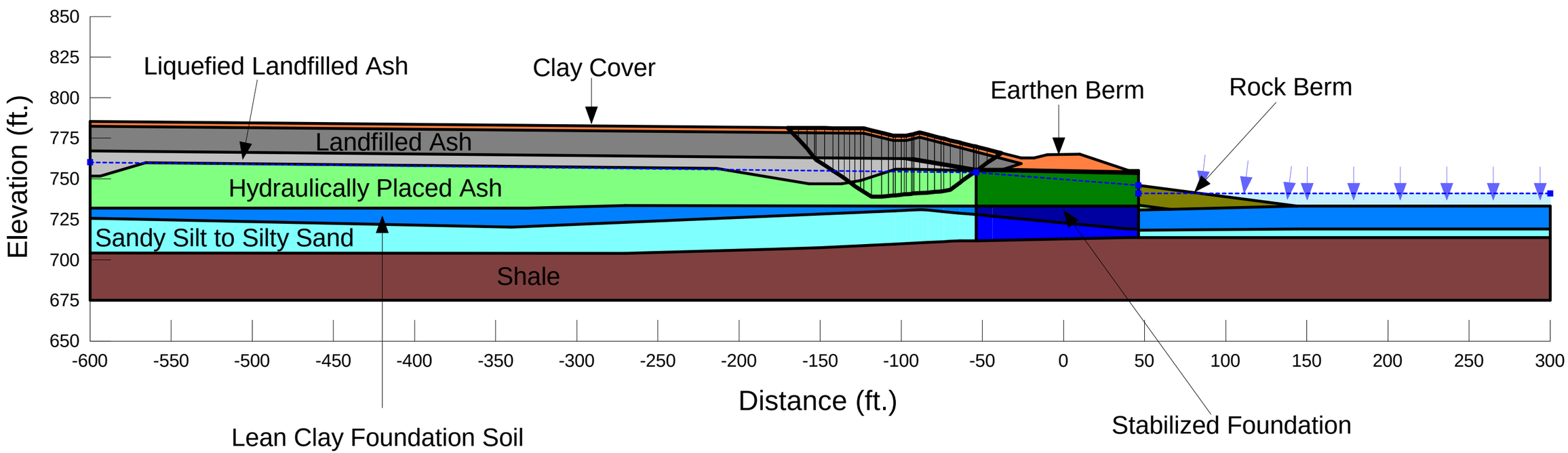

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Figure 3.B -- Case 3, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.03
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.03
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=1.3
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.07
Center = (25.023, 1222.56)
Radius = 163.4596

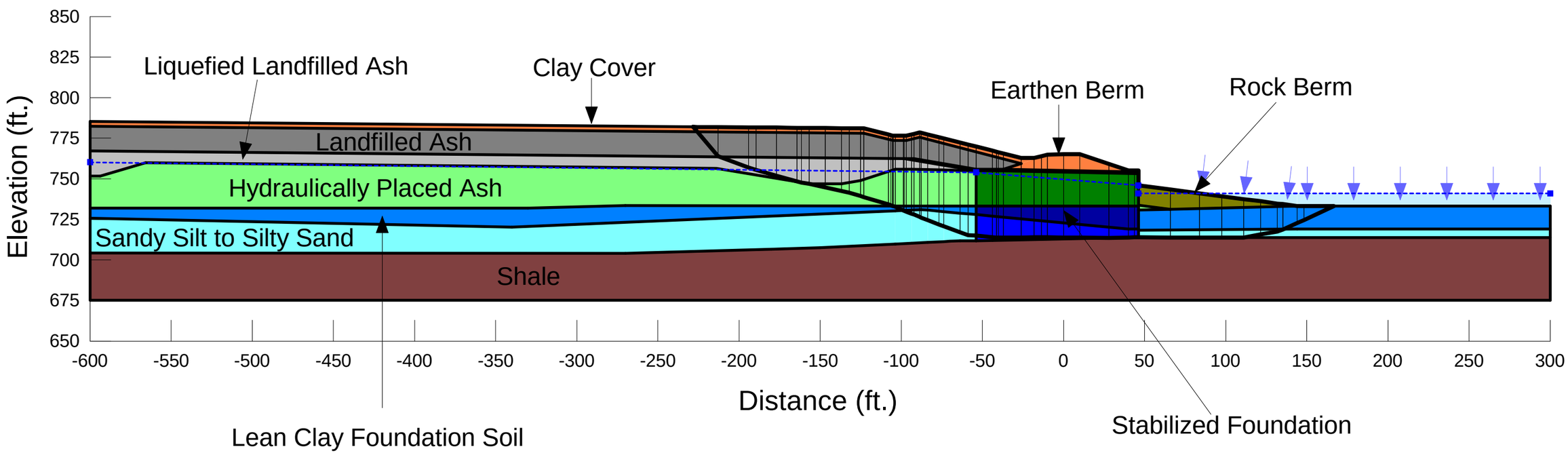

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Figure 4.A -- Case 4, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.03
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.03
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=1.3
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.20
Center = (-113.624, 839.936)
Radius = 70.9391

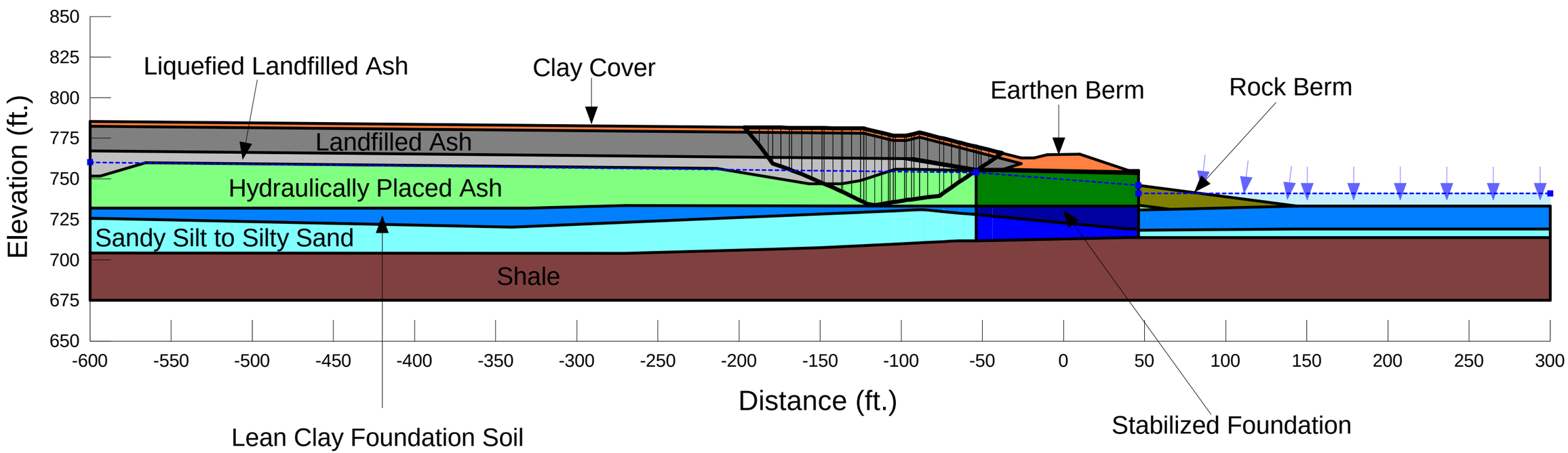

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Figure 4.B -- Case 4, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.09
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.09
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=3.8
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.15
Center = (25.023, 1222.56)
Radius = 157.2252

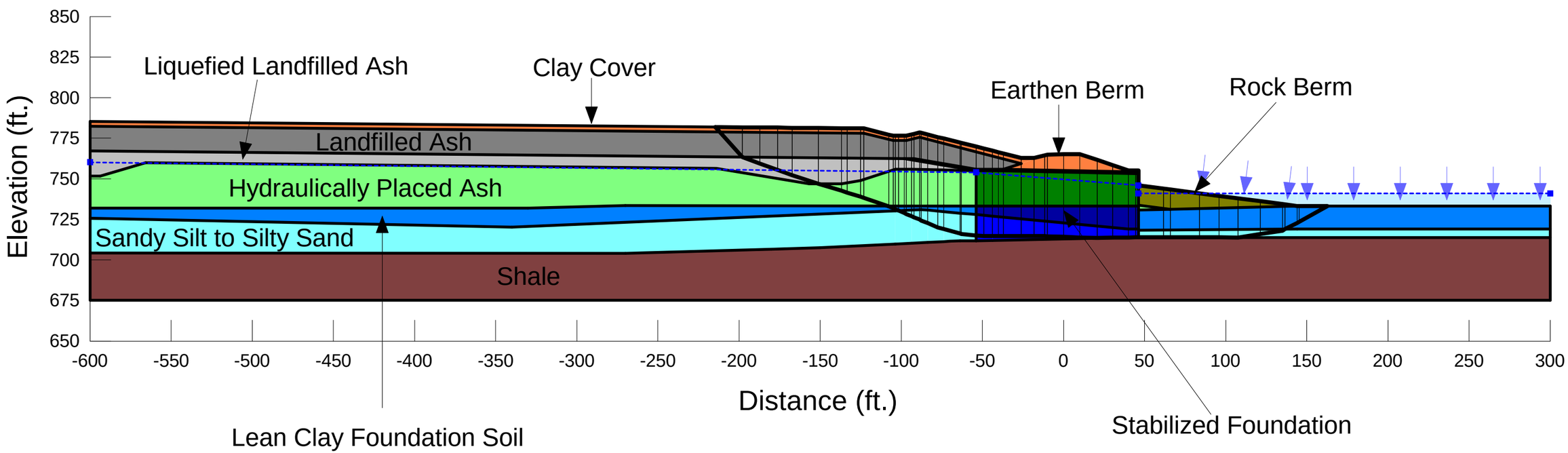

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Figure 5.A -- Case 5, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.09
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.09
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=3.8
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.85
Center = (-101.687, 825.088)
Radius = 59.48898

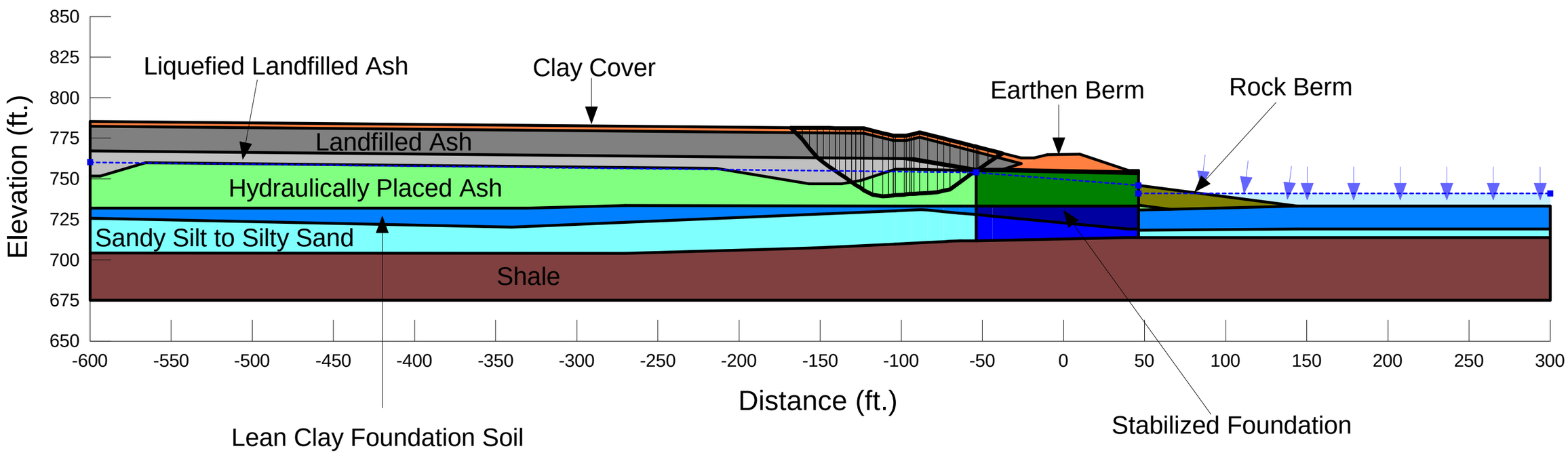

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Figure 5.B -- Case 5, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=16.8
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=12.6
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.99
Center = (16.201, 1403.81)
Radius = 171.0732

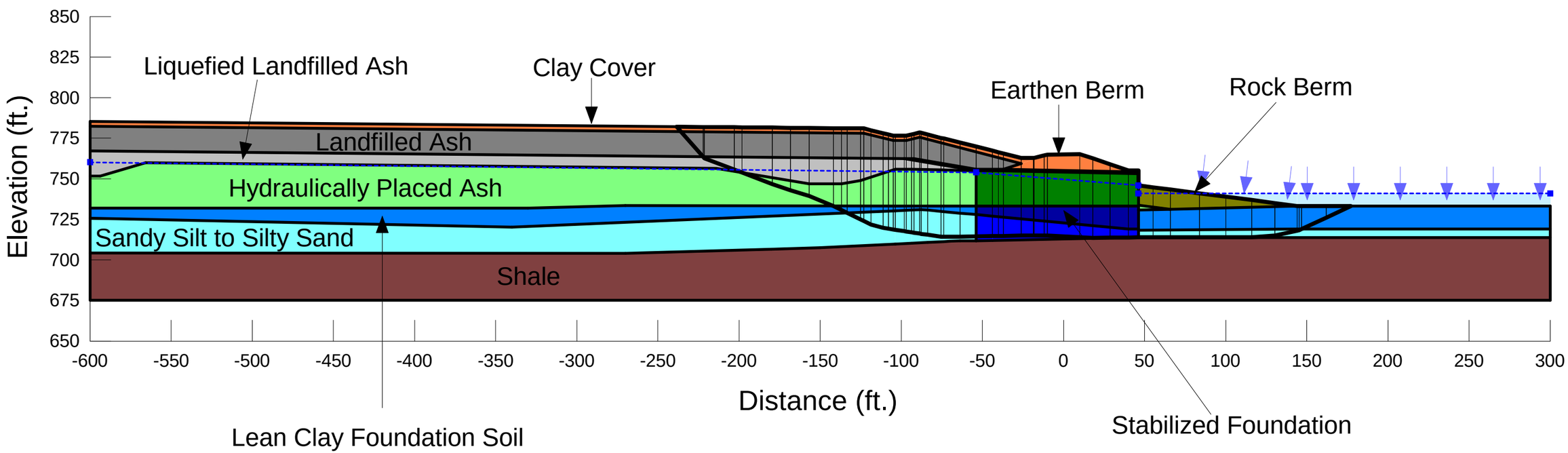

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Figure 6.A -- Case 6, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=16.8
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=12.6
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

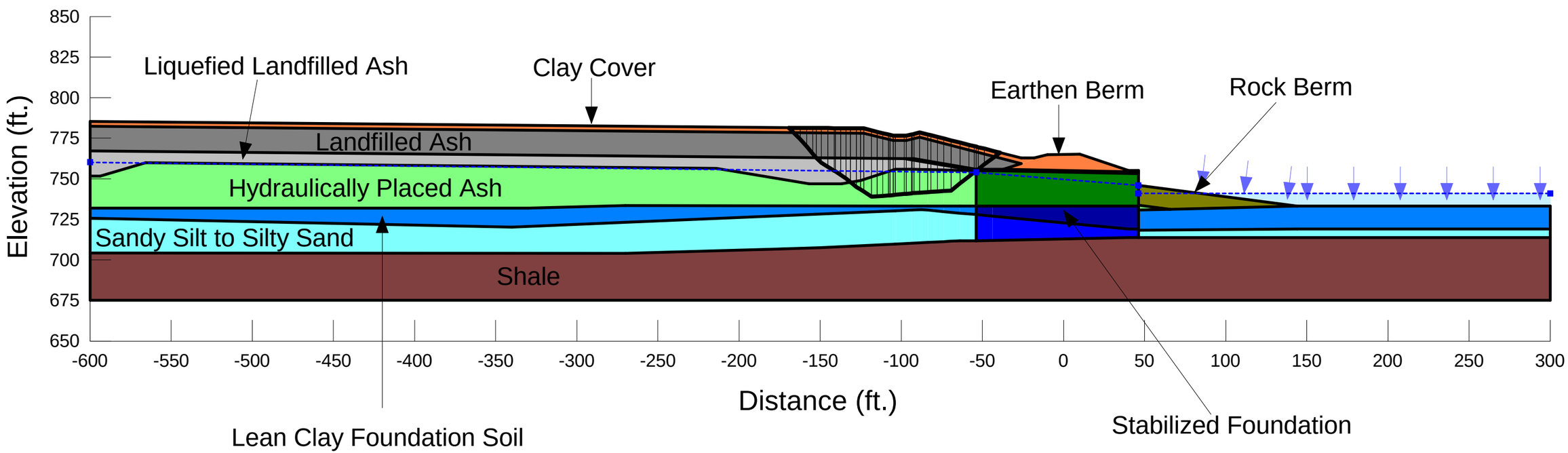

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Figure 6.B -- Case 6, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=39.2
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=31.1
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.20
Center = (25.023, 1222.56)
Radius = 162.4847

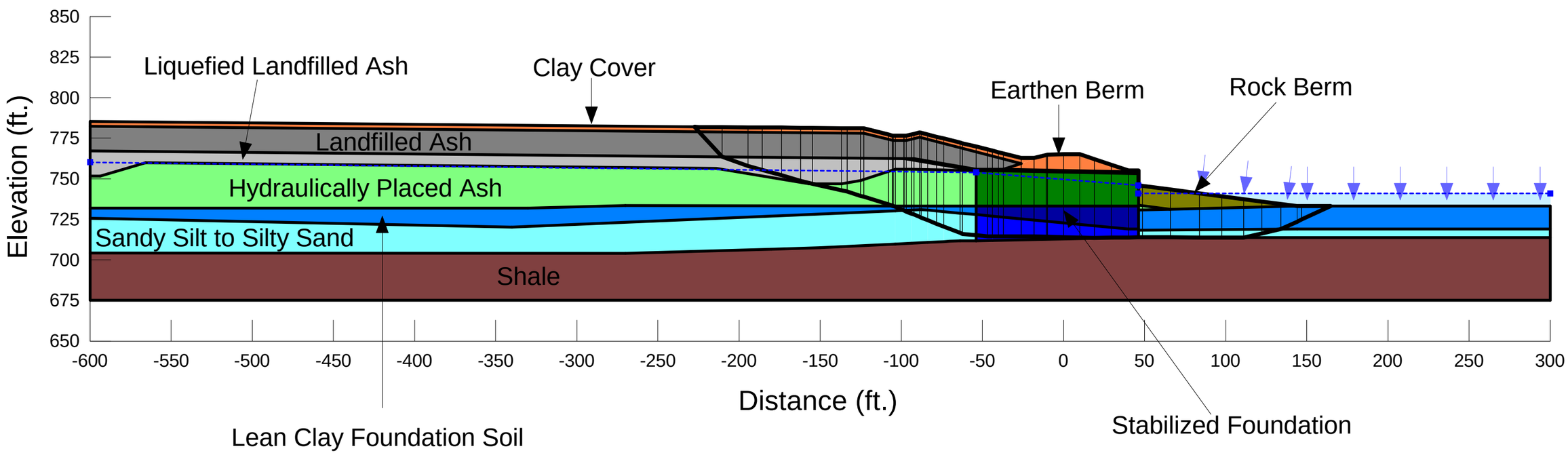

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Figure 7.A -- Case 7, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=39.2
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=31.1
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

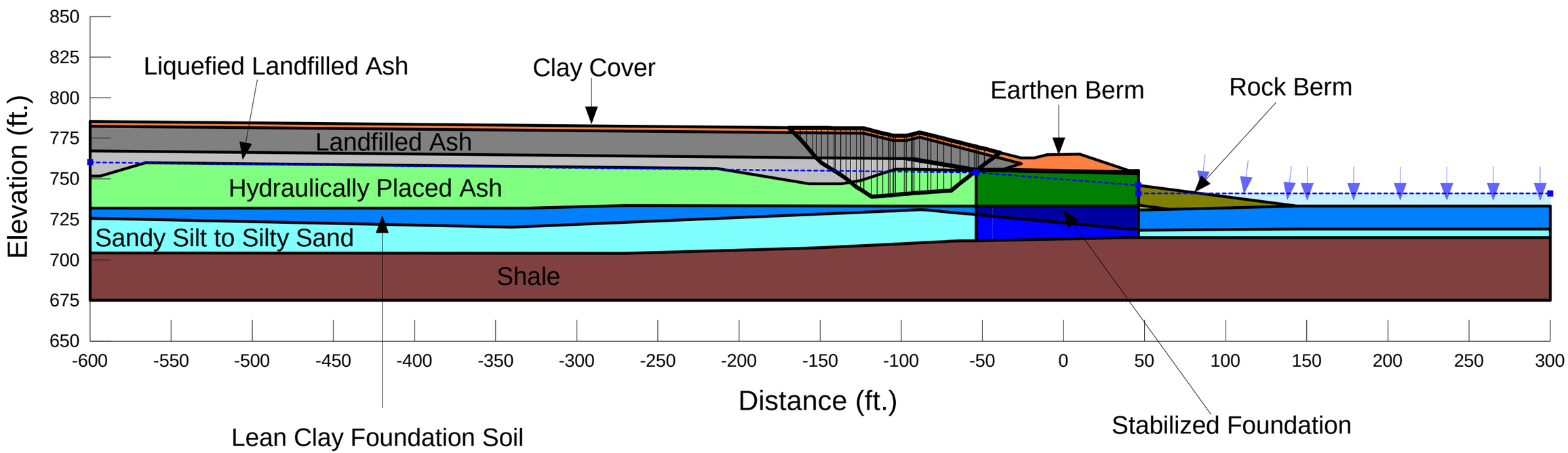

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Figure 7.B -- Case 7, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.03
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=1.3
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.00
Center = (25.023, 1222.56)
Radius = 161.1685

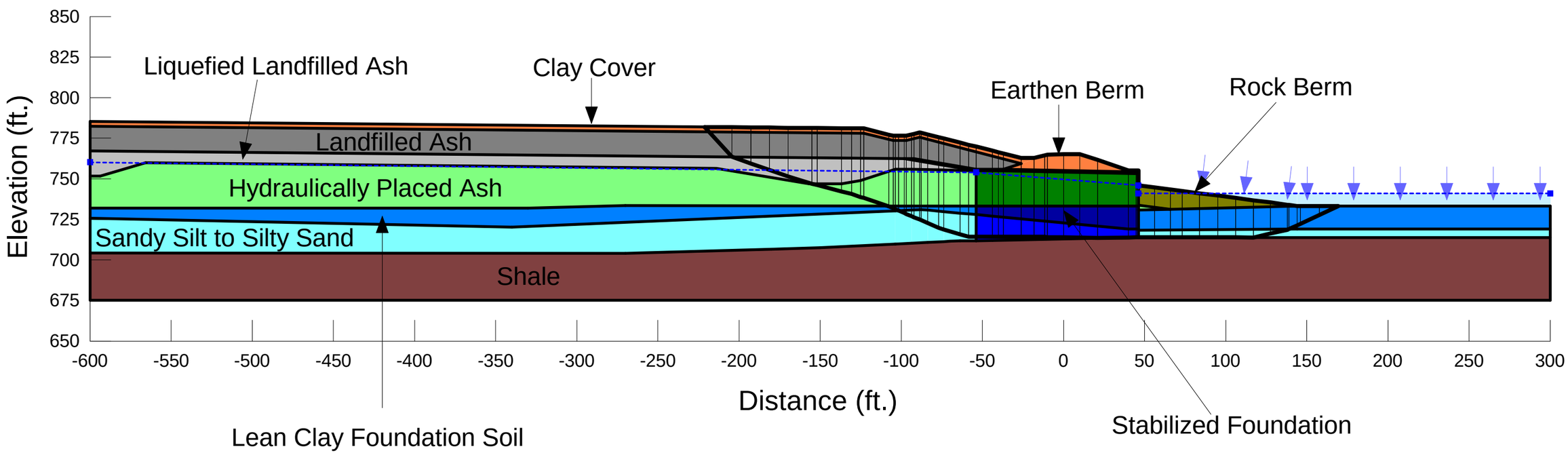

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Figure 8.A -- Case 8, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.03
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=1.3
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

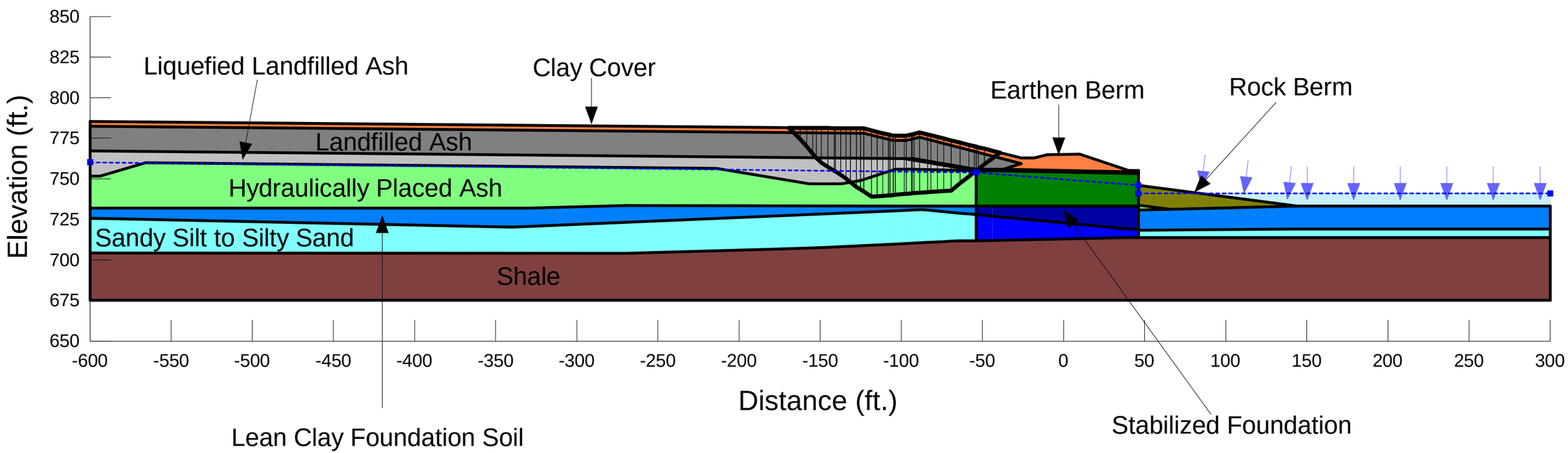

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Figure 8.B -- Case 8, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.09
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=3.8
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.21
Center = (25.023, 1222.56)
Radius = 161.3517

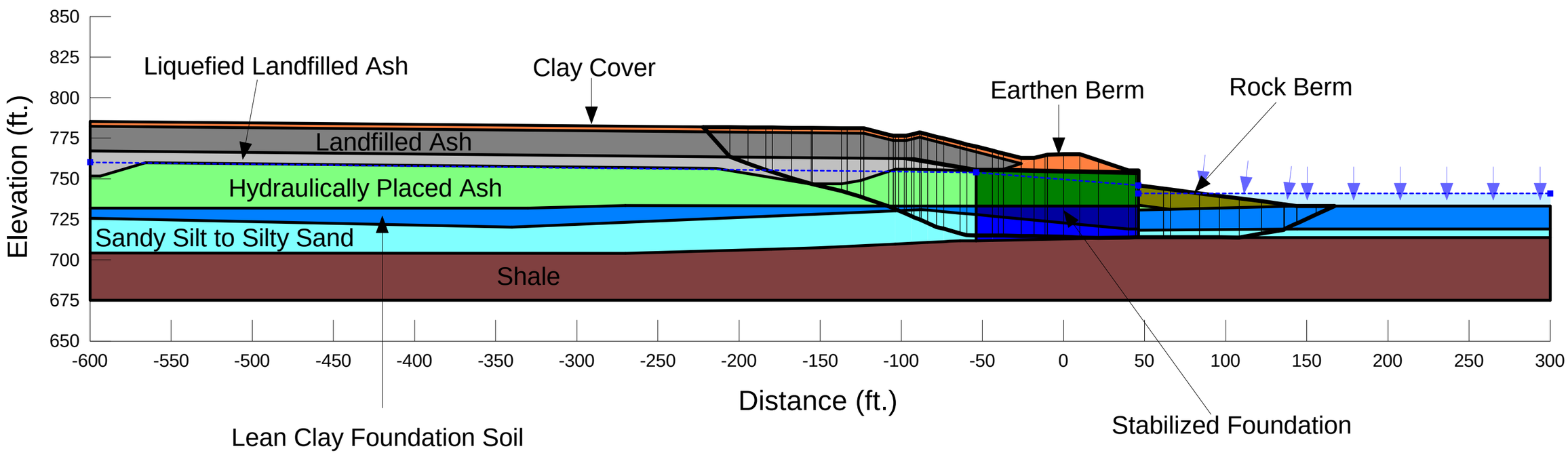

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Figure 9.A -- Case 9, Deep Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.09
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2995; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2995; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2995; phi=3.8
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

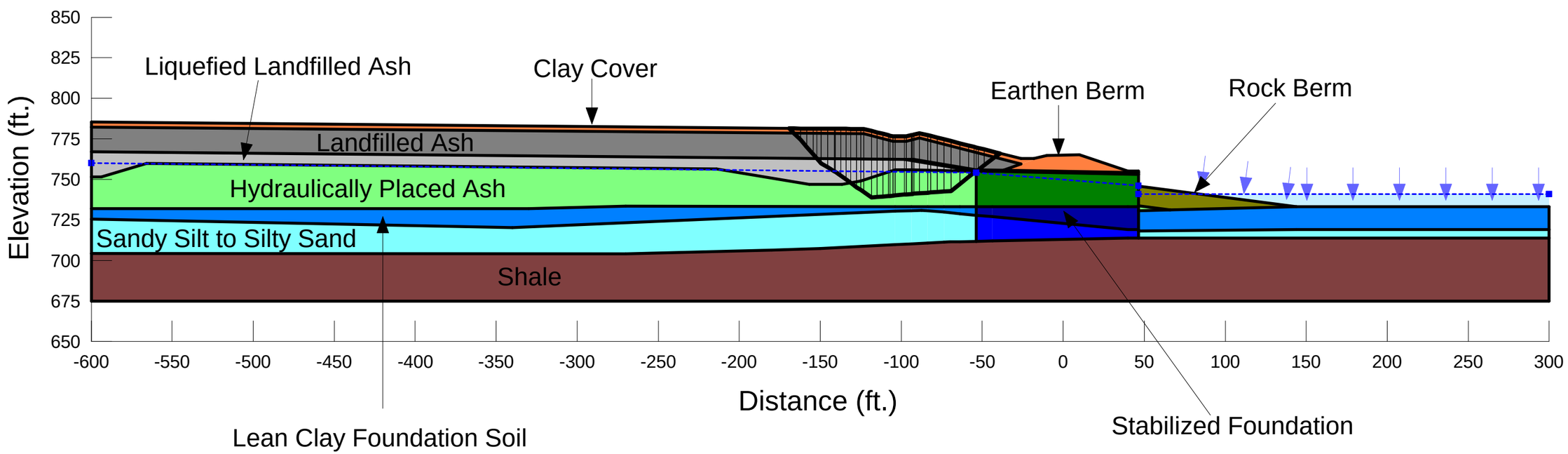

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Figure 9.B -- Case 9, Shallow Failure

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2396; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2396; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2396; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.79
Center = (25.023, 1222.56)
Radius = 161.0358

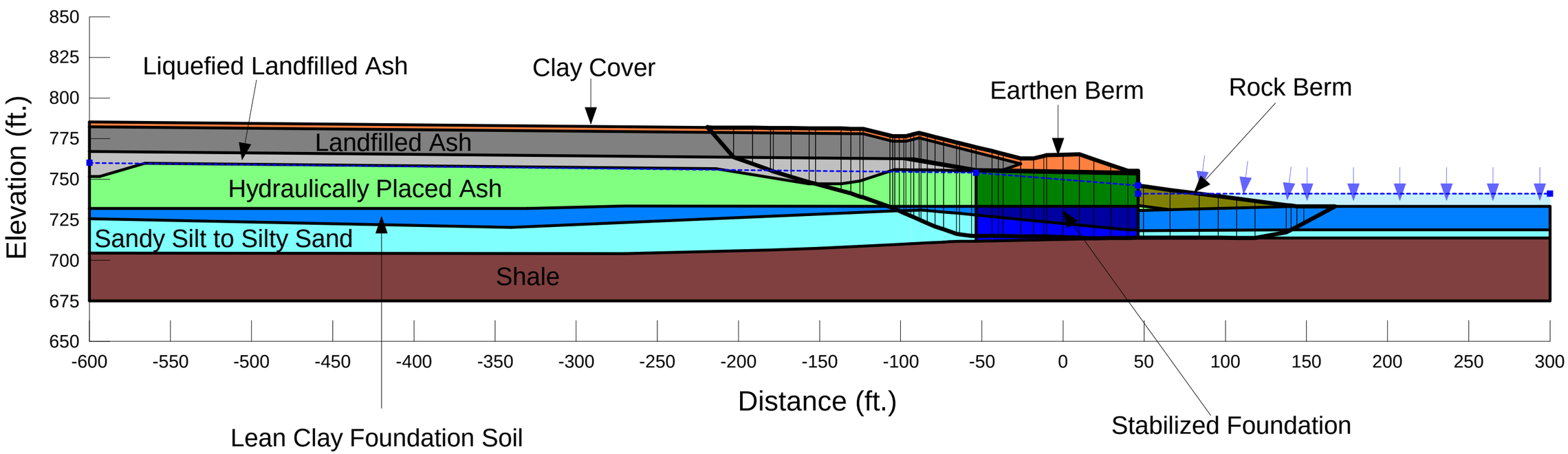

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Figure 10.1A -- Case 10, Deep Failure (Soilcrete COV = 20%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2396; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2396; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2396; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.54
Center = (-101.687, 825.088)
Radius = 60.55869

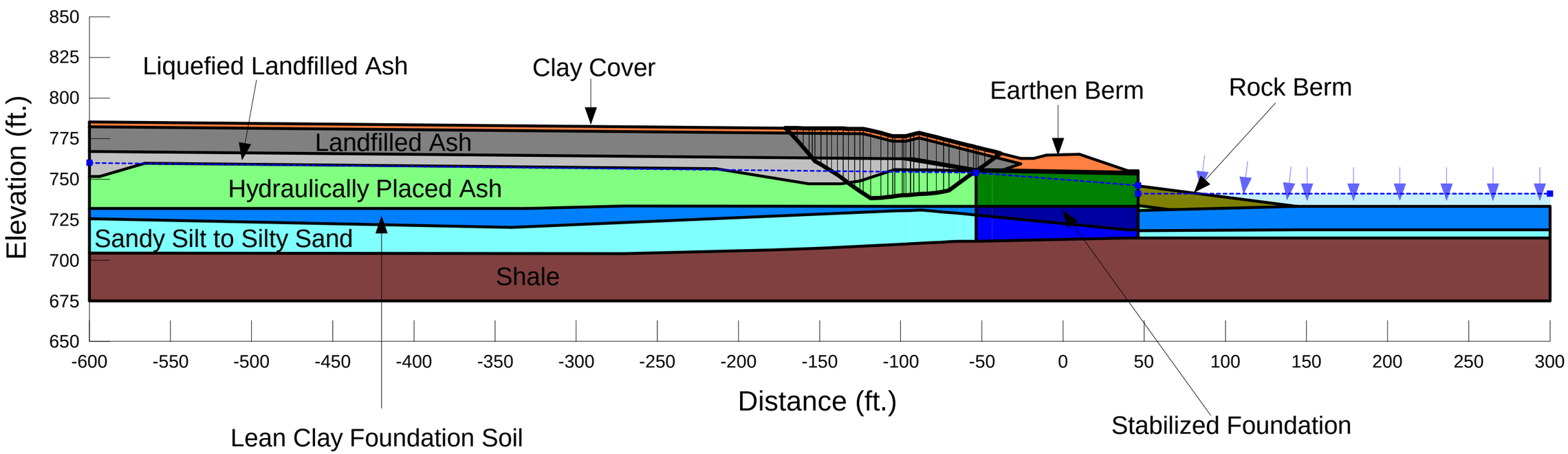

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Figure 10.1B -- Case 10, Shallow Failure (Soilcrete COV = 20%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2097; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2097; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2097; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.63
Center = (25.023, 1222.56)
Radius = 161.6294

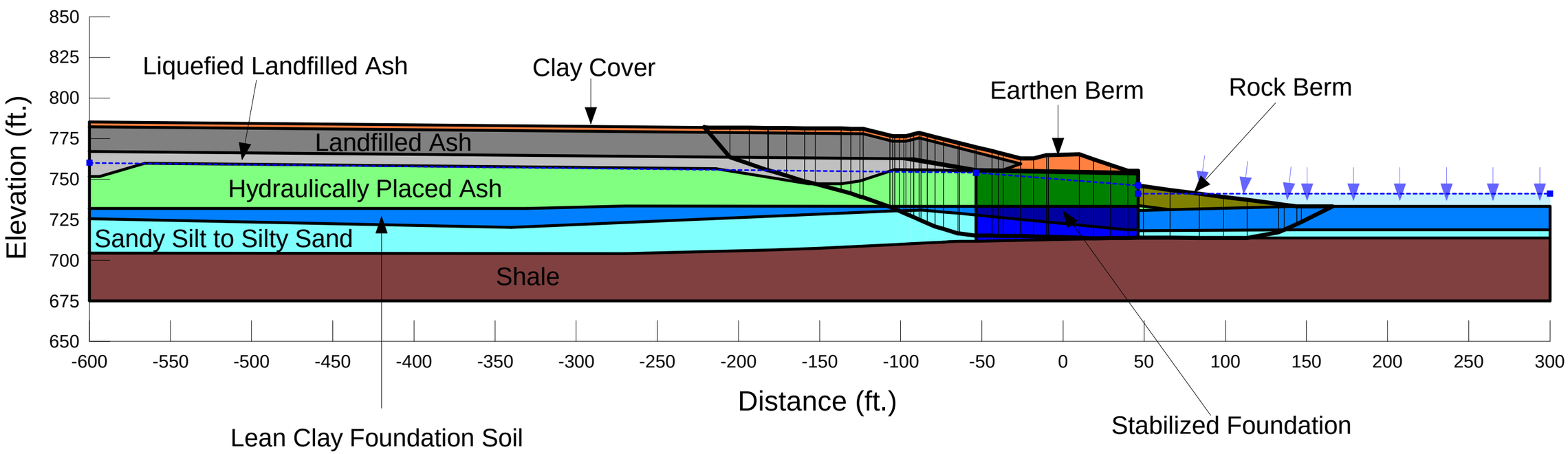

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Figure 10.2A -- Case 10, Deep Failure (Soilcrete COV = 30%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=2097; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=2097; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=2097; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.54
Center = (-101.687, 825.088)
Radius = 60.55869

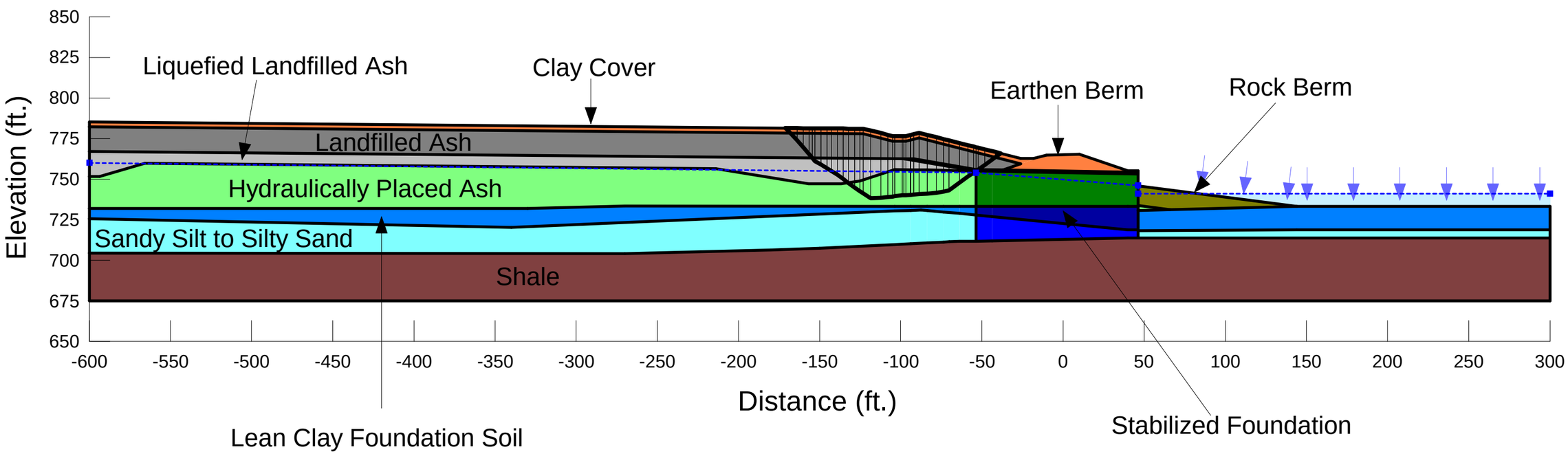

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Figure 10.2B -- Case 10, Shallow Failure (Soilcrete COV = 30%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1797; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1797; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1797; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.48
Center = (25.023, 1222.56)
Radius = 159.2499

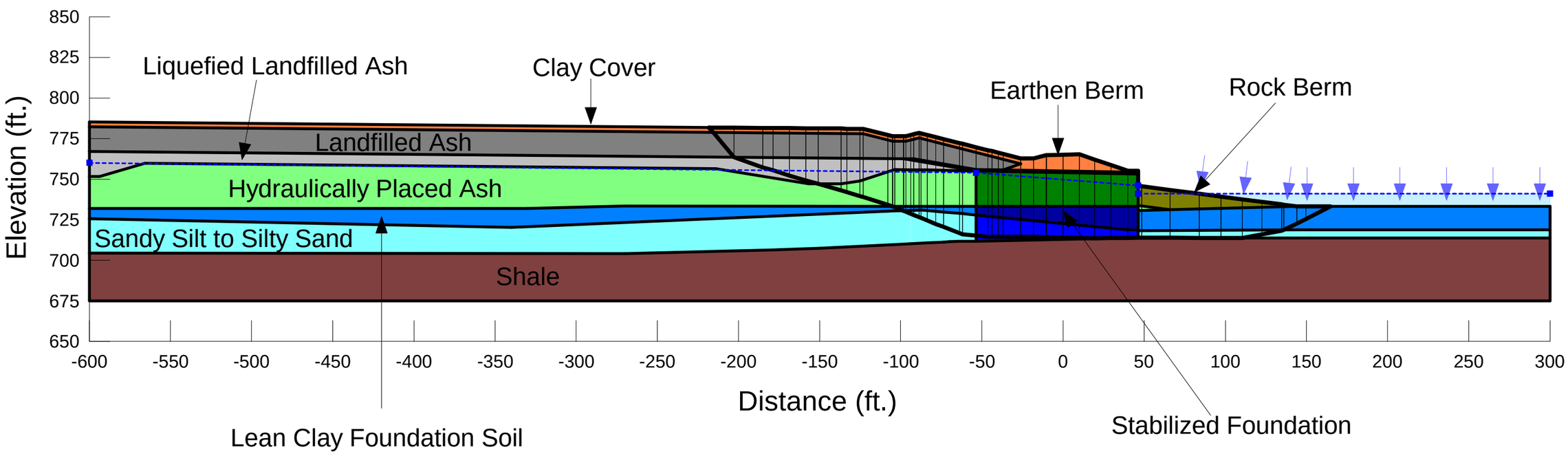

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Figure 10.3A -- Case 10, Deep Failure (Soilcrete COV = 40%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1797; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1797; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1797; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.54
Center = (-101.687, 825.088)
Radius = 60.55869

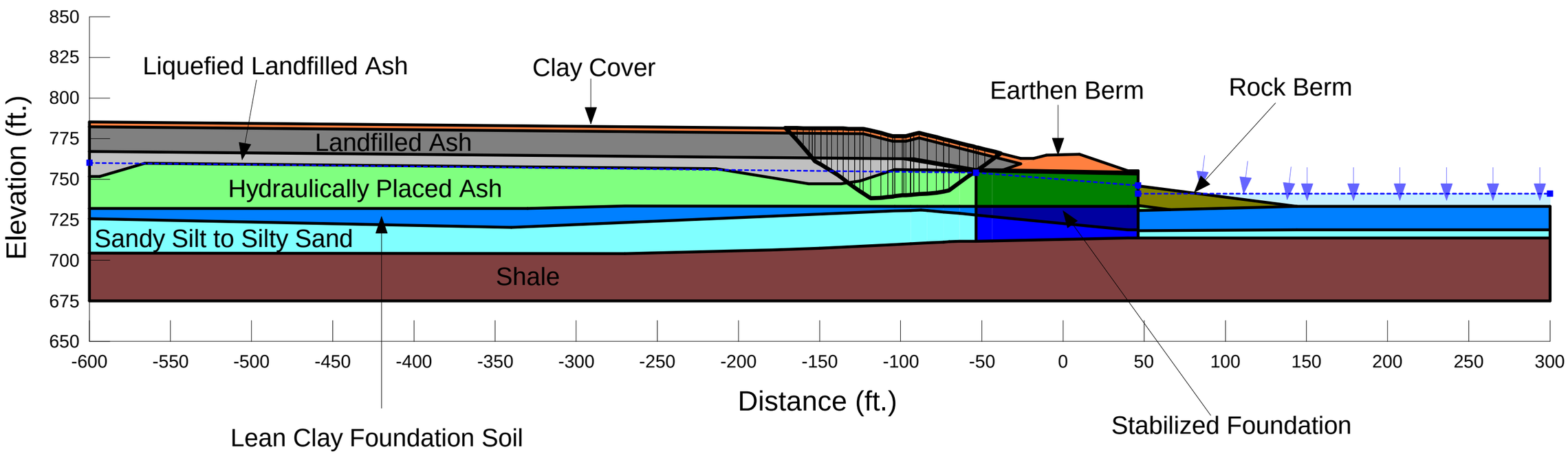

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Figure 10.3B -- Case 10, Shallow Failure (Soilcrete COV = 40%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1498; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1498; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1498; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.32
Center = (37.647, 1217.6)
Radius = 157.5545

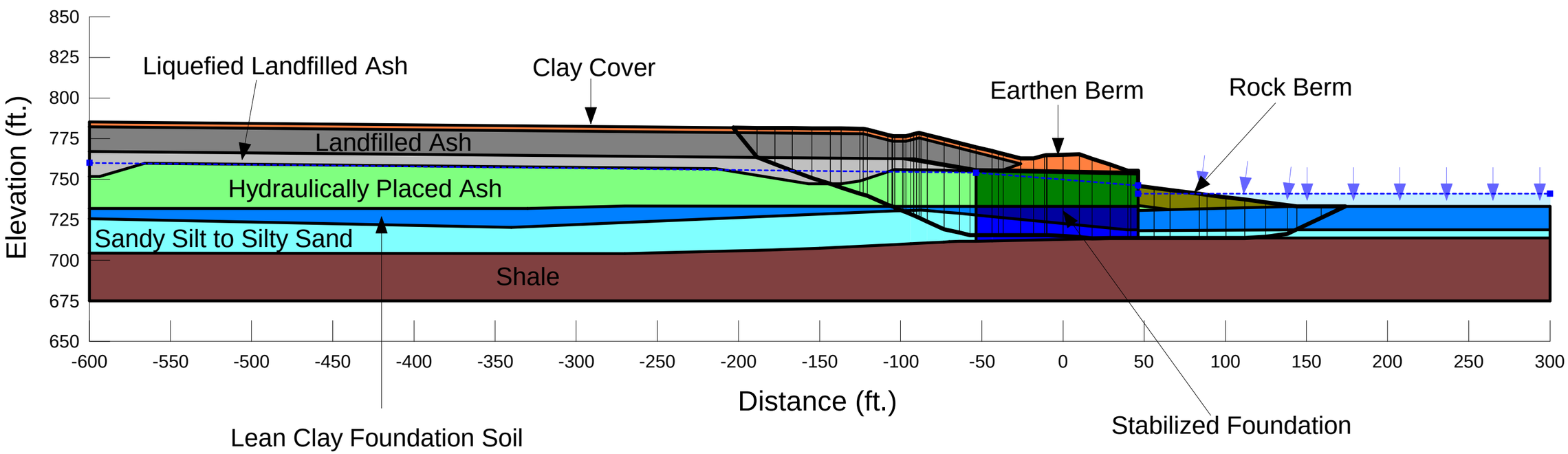

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Figure 10.4A -- Case 10, Deep Failure (Soilcrete COV = 50%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1498; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1498; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1498; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.53
Center = (-101.687, 825.088)
Radius = 60.15471

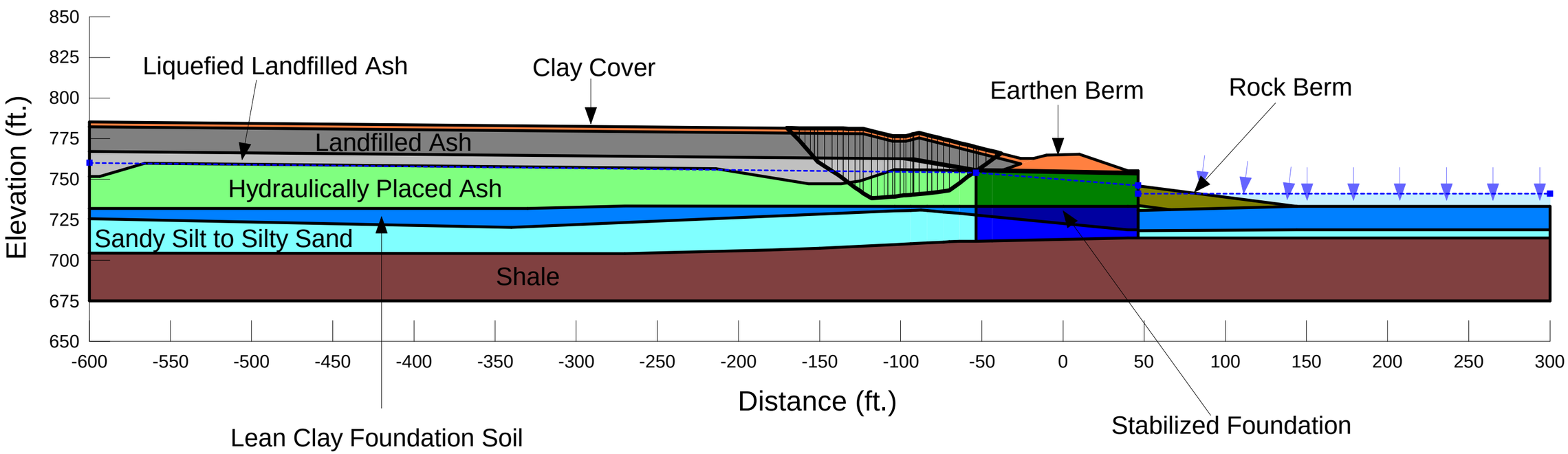

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Figure 10.4B -- Case 10, Shallow Failure (Soilcrete COV = 50%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1198; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1198; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1198; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.17
Center = (42.688, 1217.71)
Radius = 152.9634

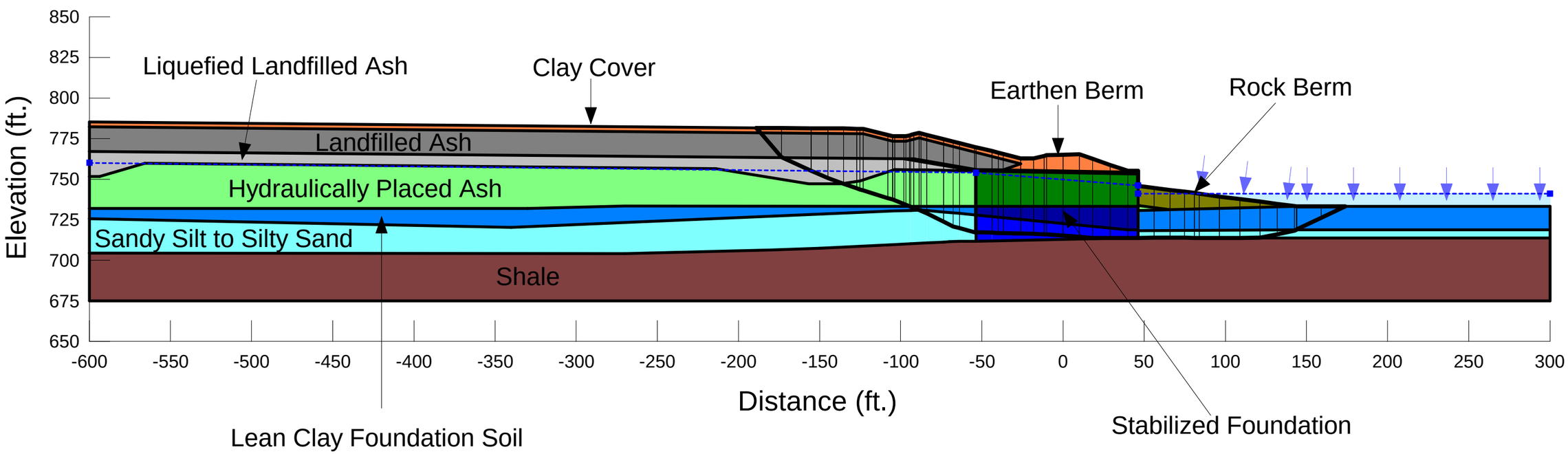

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Figure 10.5A -- Case 10, Deep Failure (Soilcrete COV = 60%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=1198; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=1198; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=1198; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.54
Center = (-104.209, 826.696)
Radius = 62.63323

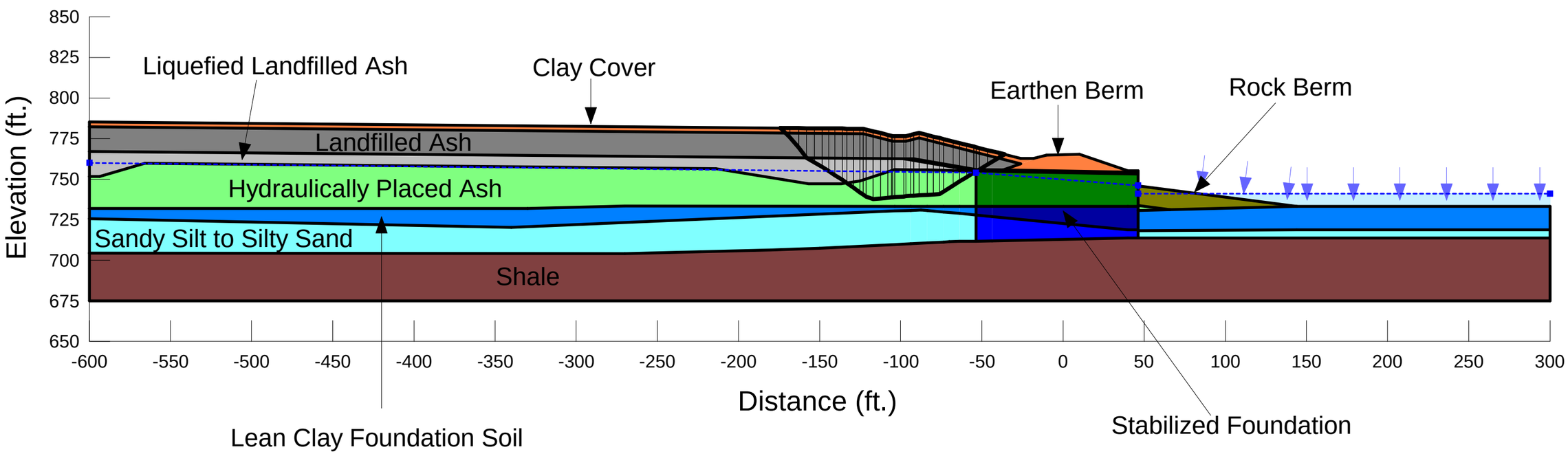

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Figure 10.5B -- Case 10, Shallow Failure (Soilcrete COV = 60%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=899; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=899; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=899; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.01
Center = (42.688, 1217.71)
Radius = 156.9779

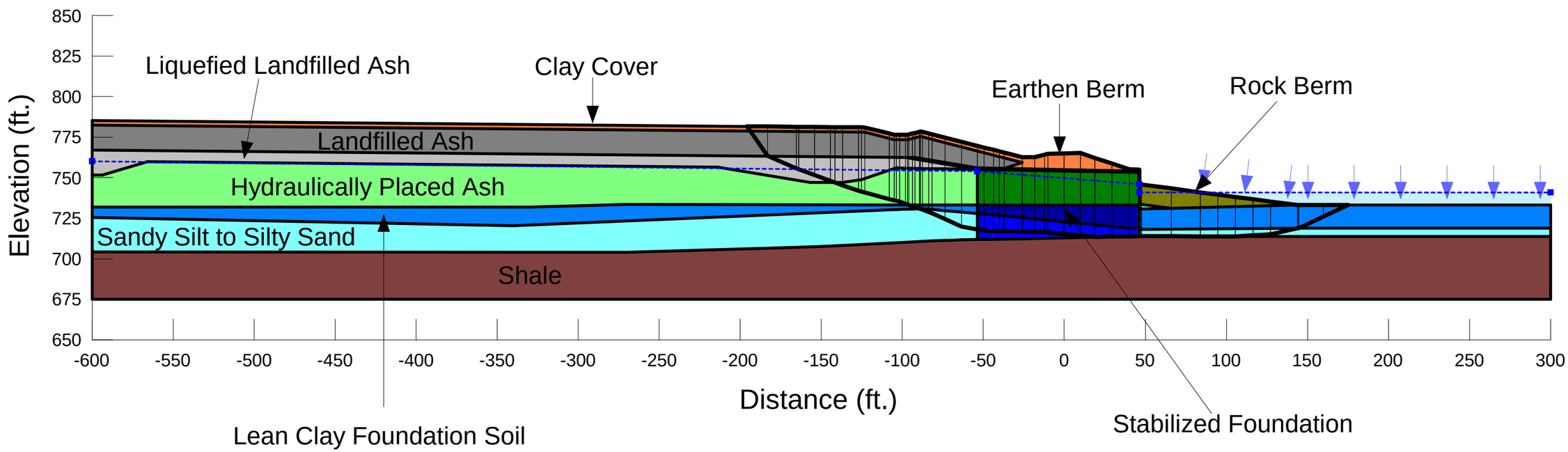

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Figure 10.6A -- Case 10, Deep Failure (Soilcrete COV = 70%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=899; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=899; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=899; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.49
Center = (-100.723, 831.701)
Radius = 70.98495

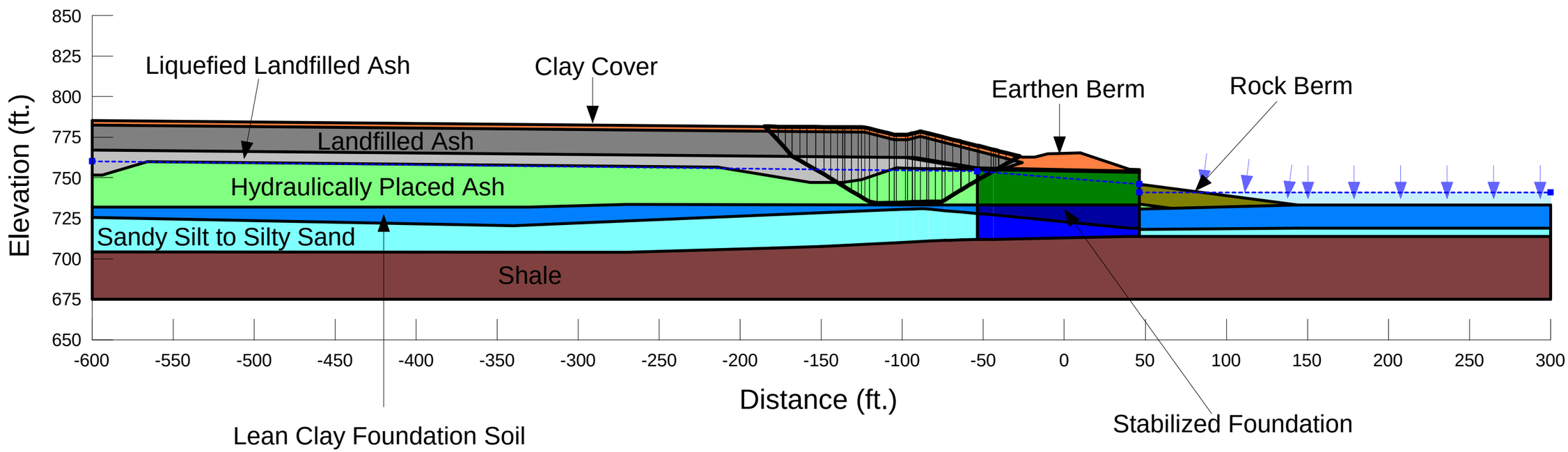

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Figure 10.6B -- Case 10, Shallow Failure (Soilcrete COV = 70%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=3594; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=3594; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=3594; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.39
Center = (28.782, 1397.83)
Radius = 176.2731

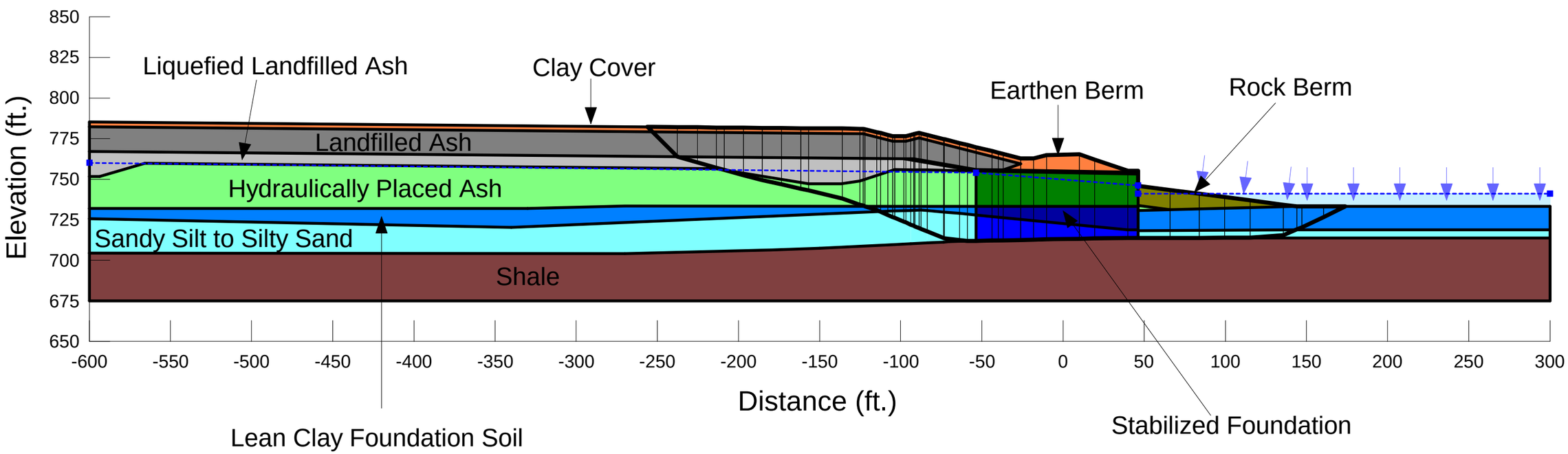

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Figure 11.1A -- Case 11, Deep Failure (Soilcrete COV = 20%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=3594; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=3594; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=3594; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

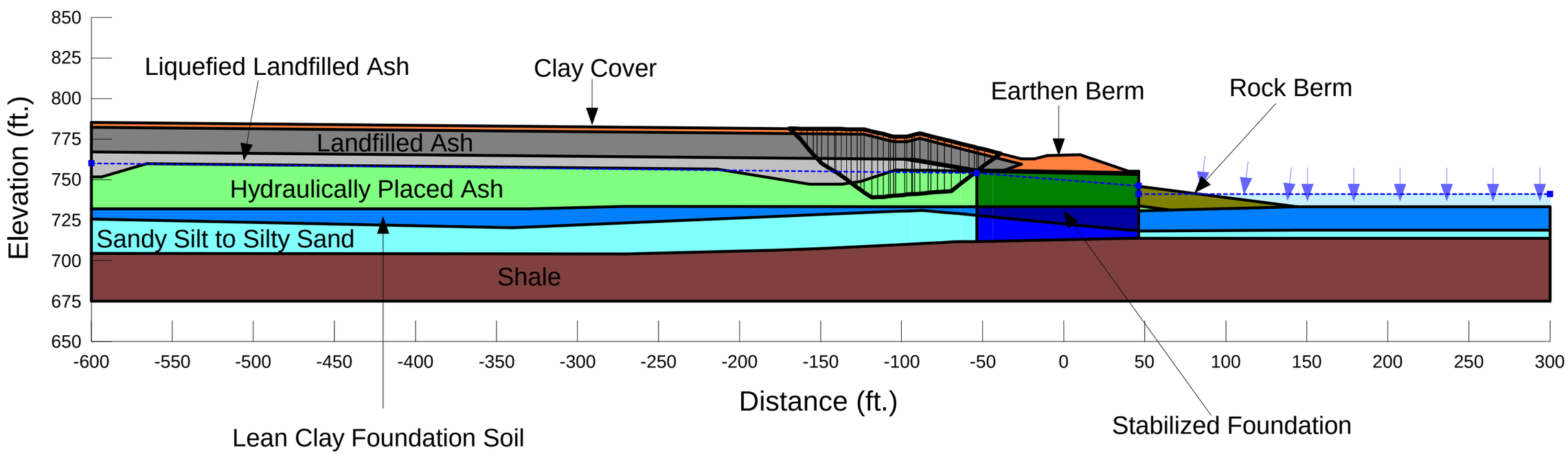

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Figure 11.1B -- Case 11, Shallow Failure (Soilcrete COV = 20%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=3894; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=3894; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=3894; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.55
Center = (33.814, 1397.98)
Radius = 172.4844

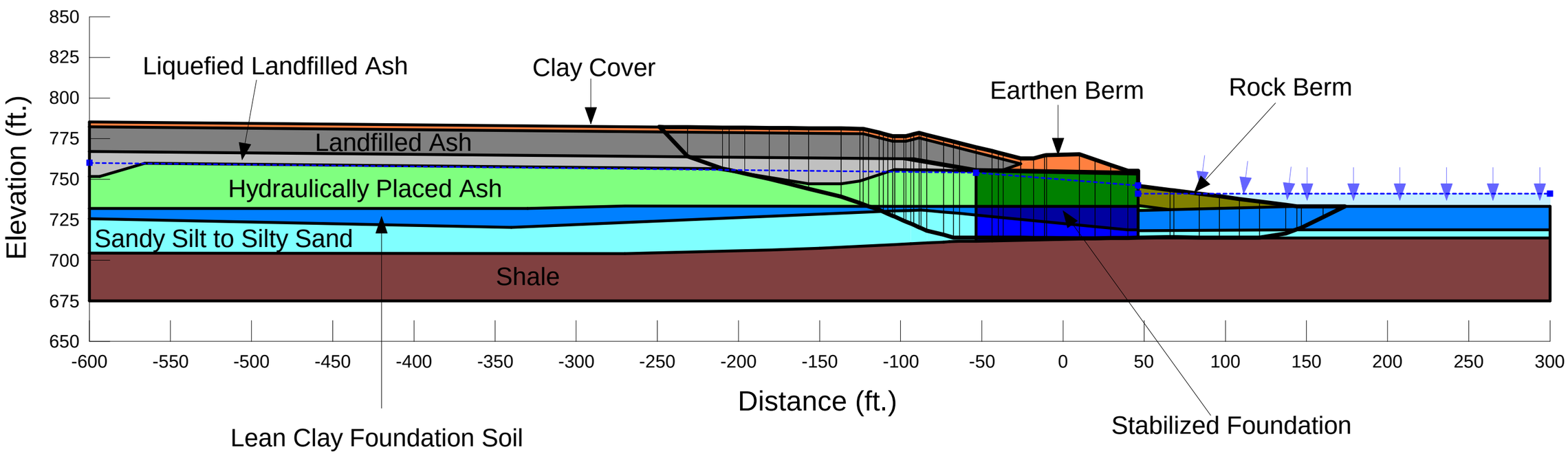

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Figure 11.2A -- Case 11, Deep Failure (Soilcrete COV = 30%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=3894; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=3894; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=3894; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

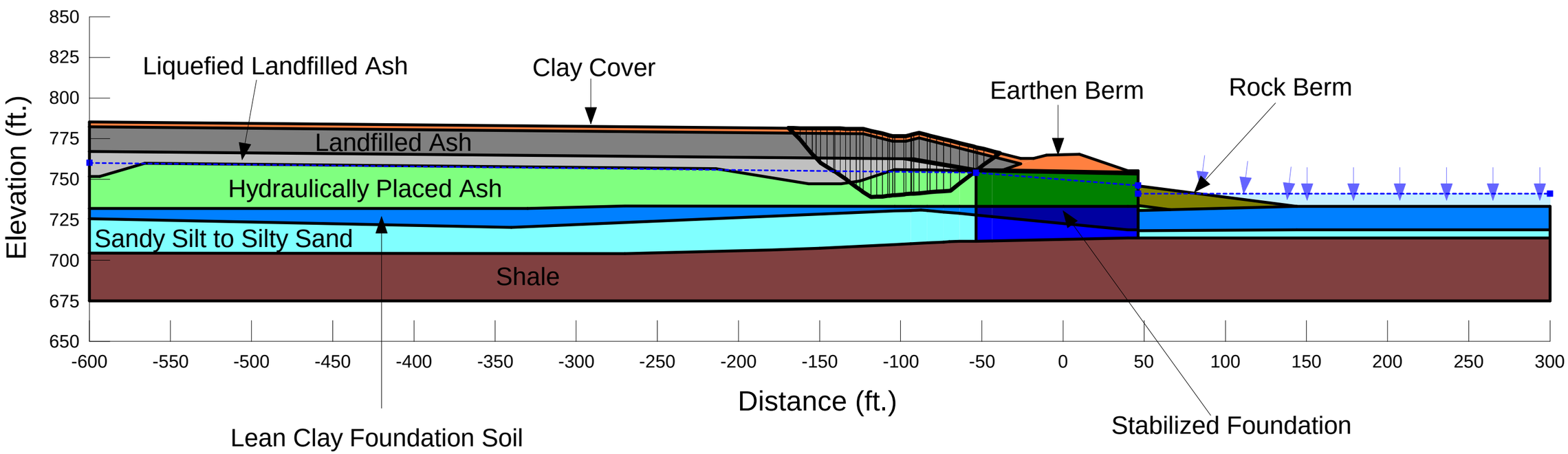

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Figure 11.2B -- Case 11, Shallow Failure (Soilcrete COV = 30%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4193; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4193; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4193; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.64
Center = (-10.362, 1253.3)
Radius = 177.2703

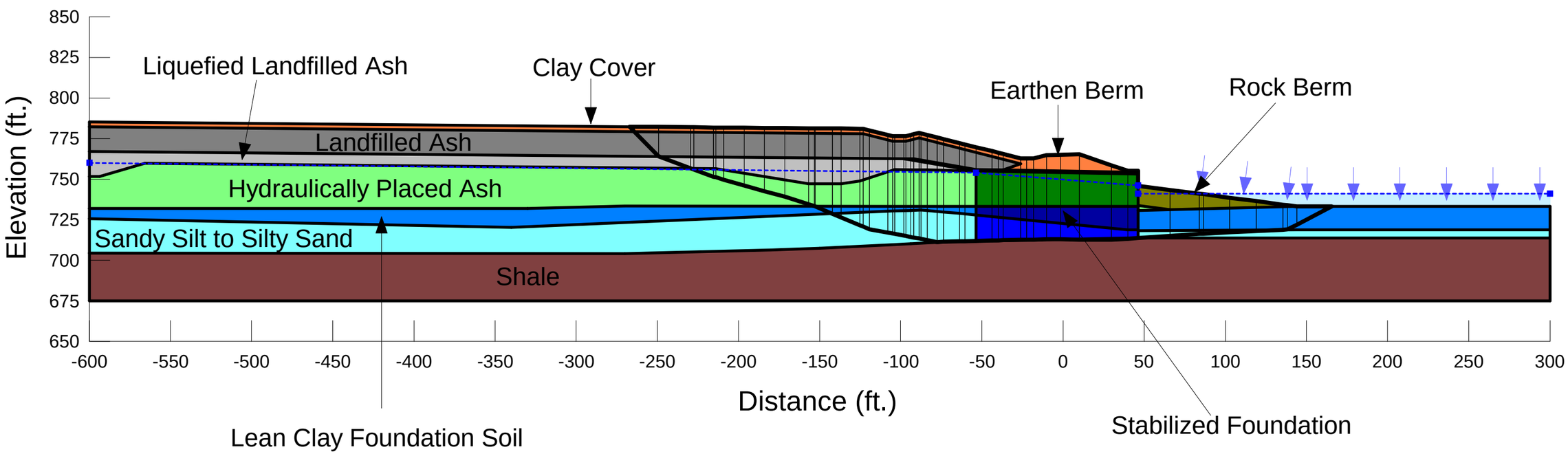

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Figure 11.3A -- Case 11, Deep Failure (Soilcrete COV = 40%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4193; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4193; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4193; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

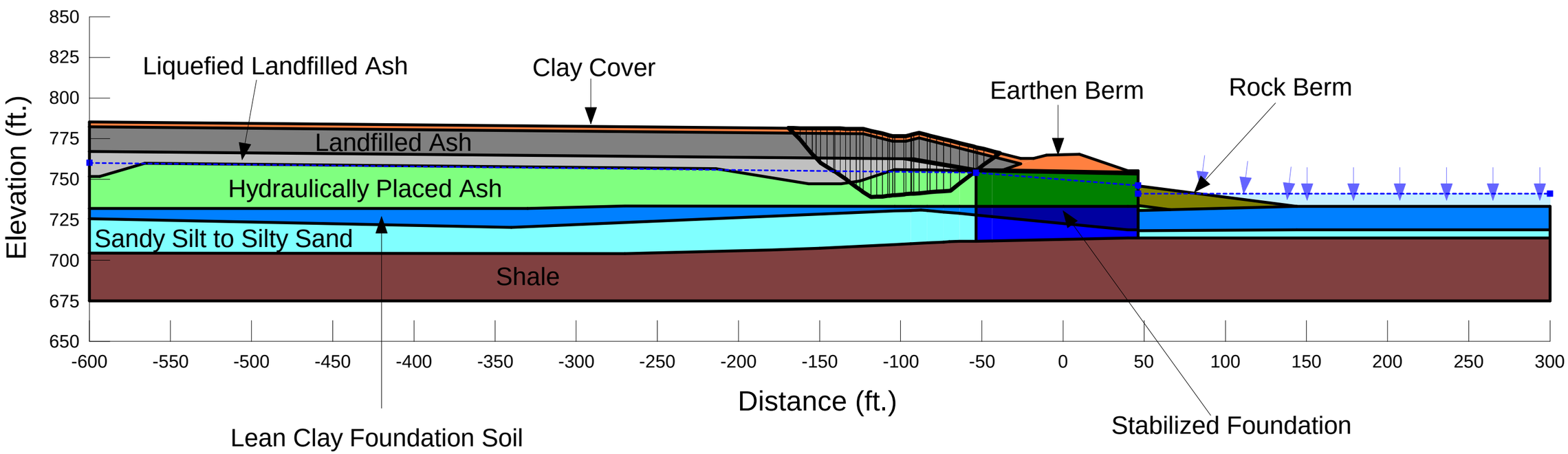

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Figure 11.3B -- Case 11, Shallow Failure (Soilcrete COV = 40%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4493; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4493; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4493; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.75
Center = (-10.362, 1253.3)
Radius = 173.9962

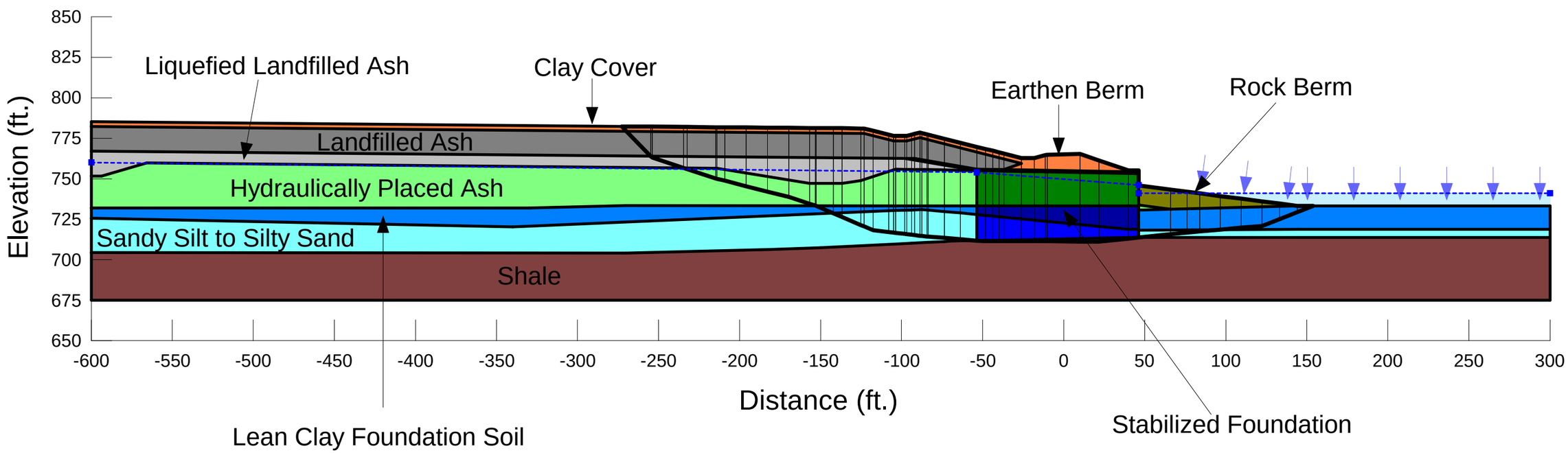

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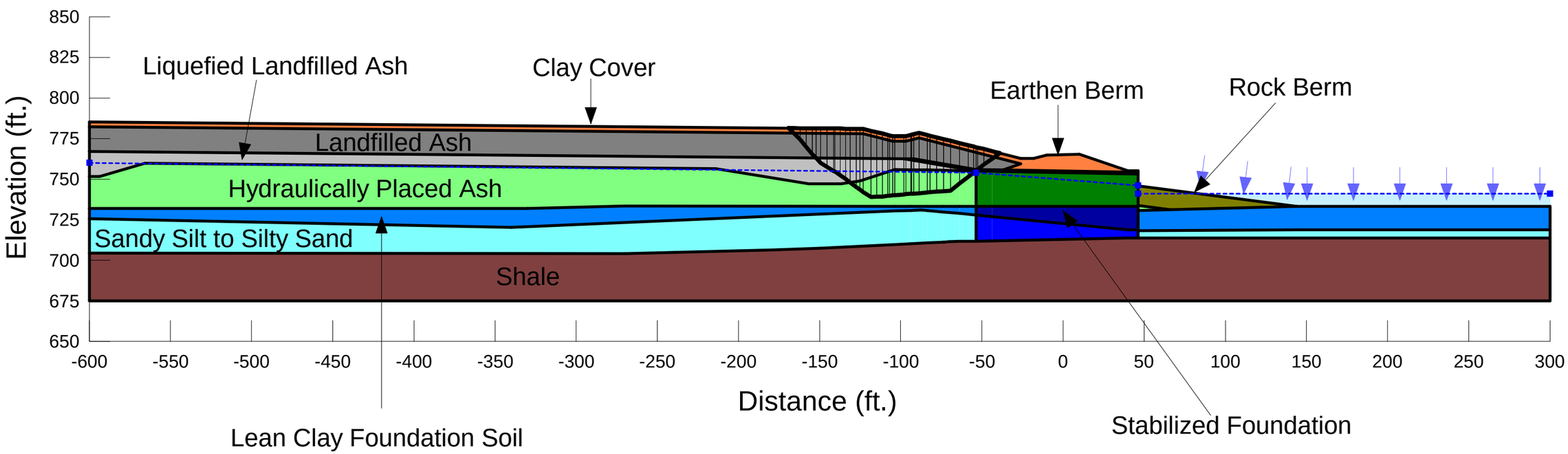
Figure 11.4A -- Case 11, Deep Failure (Soilcrete COV = 50%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4493; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4493; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4493; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399



File Name: 168+00_06_Case_11_V50.gsz
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Figure 11.4B -- Case 11, Shallow Failure (Soilcrete COV = 50%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4792; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4792; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4792; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.78
Center = (-10.196, 1143.64)
Radius = 160.2663

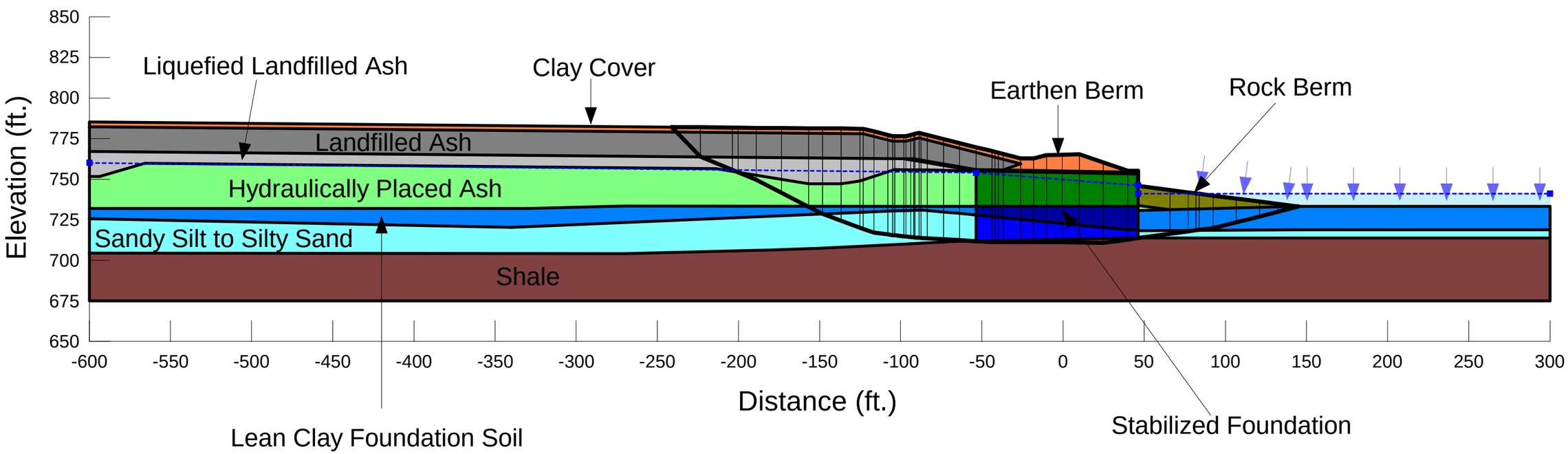

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Figure 11.5A -- Case 11, Deep Failure (Soilcrete COV = 60%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=4792; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=4792; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=4792; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

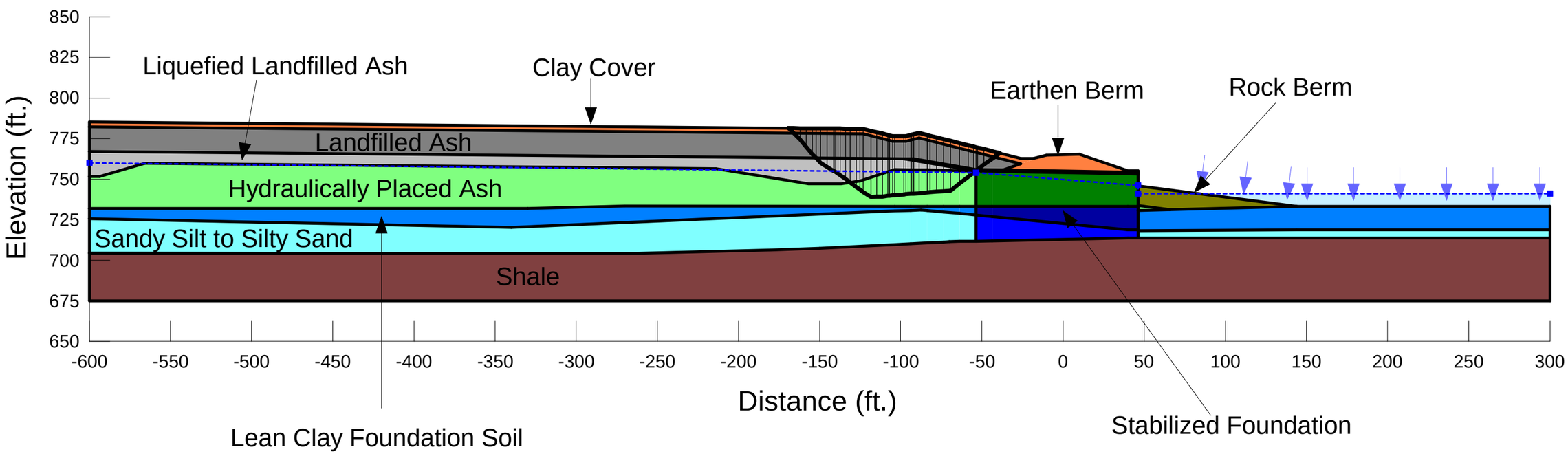

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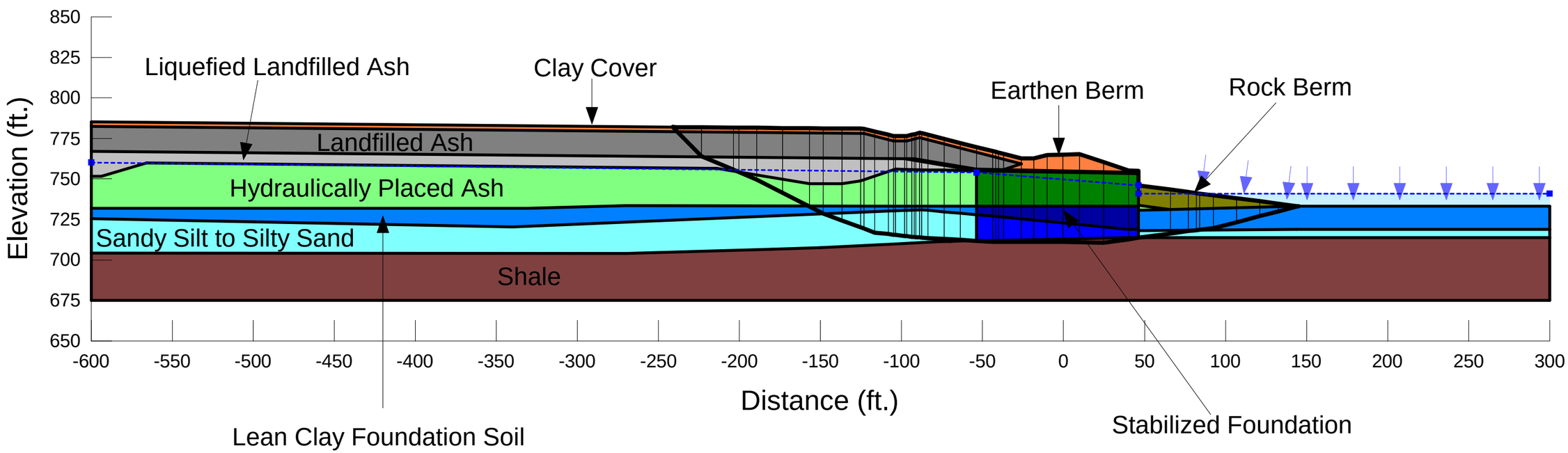
Figure 11.5B -- Case 11, Shallow Failure (Soilcrete COV = 60%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=5092; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=5092; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=5092; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 2.78
Center = (-10.196, 1143.64)
Radius = 160.2663



File Name: 168+00_06_Case_11_V70.gsz
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Figure 11.6A -- Case 11, Deep Failure (Soilcrete COV = 70%)

Material Name	Model	Unit Weight (Below/Above W.T.)	Strength Parameters
Earthen Berm	Undrained (Phi=0)	128; 125	c=1500; phi=0
Coarse Stone	Mohr-Coulomb	128; 115	c=0; phi=32
Landfilled Ash	Mohr-Coulomb	111; 109	c=0; phi=30
Liq. Landfilled Ash	S=f(overburden)	111; 111	Tau/Sigma=0.06
Hydraulically Placed Ash	S=f(overburden)	107; 100	Tau/Sigma=0.06
Lean Clay	Mohr-Coulomb	130; N/A	c=0; phi=28
Sandy Silt to Silty Sand	S=f(overburden)	128; N/A	Tau/Sigma=0.06
Shale	Mohr-Coulomb	140; N/A	c=3000; phi=20
Stab. Hyd. Ash	Mohr-Coulomb	107; 100	c=5092; phi=2.5
Stab. Lean Clay	Mohr-Coulomb	130; N/A	c=5092; phi=21.5
Stab. Silt to Silty Sand	Mohr-Coulomb	128; N/A	c=5092; phi=2.5
Shot Rock	Mohr-Coulomb	128; 115	c=0; phi=38

DSM Zone Width = 100 feet
Area Replacement Ratio = 26%

Factor of Safety (Opt.) = 1.55
Center = (-101.687, 825.088)
Radius = 59.48399

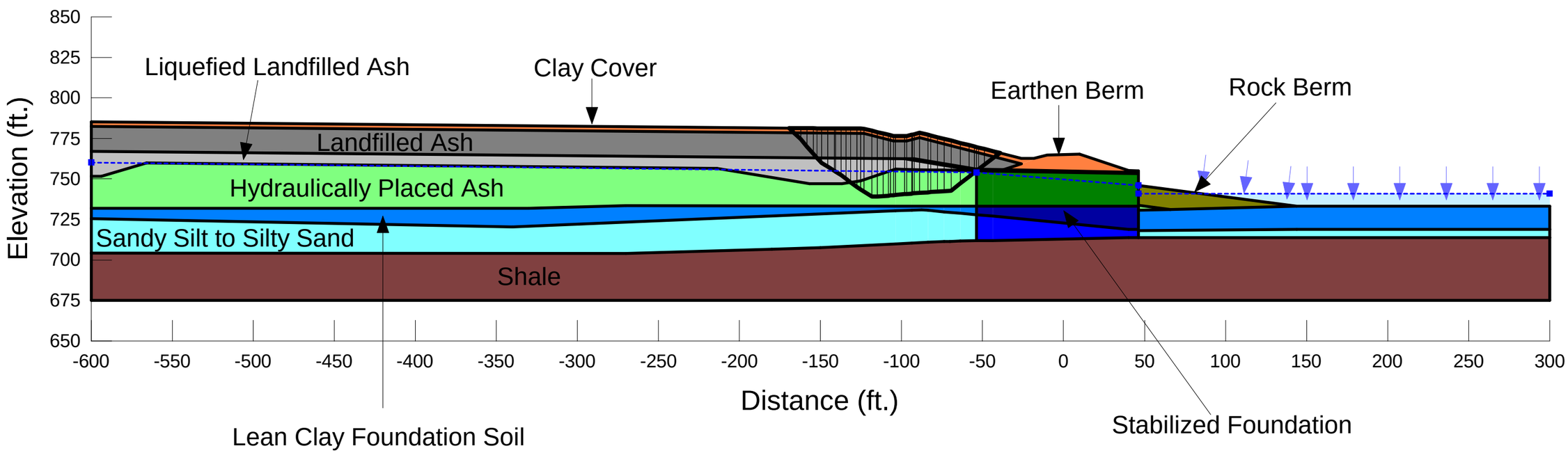

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Figure 11.6B -- Case 11, Shallow Failure (Soilcrete COV = 70%)