Subcontractor Report

**Subsidence Above In Situ
Vitrification: Evaluation for
Hanford Applications**

August 1995

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for Pacific Northwest Laboratory
under Contract DE-AC06-76RLO 1830
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Subsidence Above In Situ Vitrification: Evaluation for Hanford Applications

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MASTER

Summary

Pacific Northwest Laboratory (PNL) is evaluating methods to initiate the in situ vitrification (ISV) process in the soil subsurface. This extension of the ISV technology (which is traditionally started at the surface) has the potential to extend the ISV treatment depth beyond that currently demonstrated (approximately 6 m) and allow for selective treatment of contamination in a geologic formation.

A potential issue associated with this extension of the technology is the degree of subsidence and its effect on the ISV process. The reduction in soil porosity caused by the vitrification process results in a volume decrease of the vitrified soils, which may create a void space above the vitrification zone. Movement of in-situ materials into this void space could result in surface settlements that affect the ISV process and/or processing equipment.

Golder Associates, Inc., (Redmond, Washington) evaluated the potential for subsidence events during application of ISV in the soil subsurface. Given the assumptions for material properties of the Hanford soil (both native and affected by the ISV process), the analysis and mechanisms considered lead to the following postulated scenarios:

- Surface settlements are not expected above an ISV melt radius of 5 ft and an initiation depth of 15 ft.
- For melt radii of 10 to 15 ft, surface settlements of 5 to 10 in. are likely.
- Horizontal movement at the surface during subsidence is predicted to be minimal.
- Additional data for the properties of in-situ and fused materials are needed to increase the precision of the subsidence analysis.

Settlements greater than that predicted could occur for mechanisms not evaluated in this report. These additional mechanisms were not evaluated based on limited PNL experience indicating they were not credible. Further data is needed to determine if these additional mechanisms require analysis. The analysis was performed for application of ISV in the soil subsurface at Hanford or in Hanford-type soils. Further analysis is required before demonstration of the technology extension for other soil types.

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Contents

Summary	iii
Acknowledgments	v
1.0 Introduction	1.1
2.0 Conclusions and Recommendations	2.1
3.0 Subsidence Analyses	3.1
3.1 Assumptions And Material Properties	3.1
3.1.1 Assumed Pilot-Scale Geometry	3.1
3.1.2 Assumed Material Properties	3.1
3.2 Subsidence Scenarios Evaluated	3.7
3.2.1 Scenario 1: Structural Bridging of Void	3.9
3.2.2 Scenario 2: Raveling and Bulking	3.10
3.3 Horizontal Movements	3.21
4.0 References	4.1
Appendix A - Failure of Fused Zone and Overlying Soils	A.1
Appendix B - Monte Carlo Simulations	B.1

Figures

3.1	Schematic of Potential ISV Pilot-Scale Test Configuration	3.2
3.2	Particle Size Distribution for PNL's ISV Test Site Soils	3.3
3.3	Raveling and Bulking Schematic for ISV Subsidence Analysis (not to scale)	3.8
3.4	Schematic for Estimating Volume of Draw	3.13
3.5	Average Subsidence for Range of Effective Bulking Factors and ISV Void Radii ..	3.15
3.6	Idealized Representation of Trough Subsidence	3.16
3.7	Subsidence at Trough Center	3.18

Tables

3.1	Soil Material Properties for ISV Subsidence Analysis	3.4
3.2	Results of Probabilistic Analysis	3.20

1.0 Introduction

Pacific Northwest Laboratory (PNL)^(a) is evaluating methods to extend the applicability of the in situ vitrification (ISV) process. One method being evaluated is the initiation of the ISV process in the soil subsurface rather than the traditional start from the surface. The subsurface initiation approach will permit extension of the ISV treatment depth beyond that currently demonstrated (approximately 6 m) and allow selective treatment of contamination in a geologic formation.

A potential issue associated with the initiation of the ISV process in the soil subsurface is the degree of subsidence and its effect on the ISV process. The reduction in soil porosity caused by the vitrification process will result in a volume decrease for the vitrified soils. Typical volume reduction observed for ISV melts initiated at the surface are on the order of 20% to 30% of the melt thickness (Luey, Roberts, and Timmerman 1993; Luey et al. 1992; Buelt et al. 1987). Movement of in-situ materials into the void space created during an ISV application in the soil subsurface could result in surface settlements that affect the ISV process and the processing equipment.

Golder Associates, Inc., (GAI) of Redmond, Washington investigated the potential for subsidence events during application of ISV in the soil subsurface. Prediction of soil subsidence above an ISV melt required the following analyses: the effect of porosity reduction during ISV, failure of fused materials surrounding the ISV melt, bulking of disturbed materials above the melt, and propagation of strains to the surface.

The subsidence analyses were performed using Hanford soil properties. Hanford soil was selected because the initial field demonstration of the new ISV application would likely be at PNL's test site (located west of the 300 Area on the Hanford Site). For the majority of the analyses, values for a pilot-scale system were used since that system is typically used for initial field demonstrations. To determine the effect of scale on the analyses, multiple radii for the ISV melt were considered, as were different initiation depths for the ISV process.

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2.0 Conclusions And Recommendations

An analysis was performed to evaluate the potential for subsidence events during application of a new ISV technique that initiates the process in the soil subsurface. Soil properties from the Hanford Site were selected for the evaluation since the first field demonstration of the new technique would likely occur at PNL's test site located on the Hanford Site. Results from the analysis provided the following conclusions:

- For the two scenarios evaluated, surface settlements are not expected for an ISV melt radius of 5 ft (typical for the pilot-scale system) and an initiation depth of 15 ft. However, at larger melt radii of 10 to 15 ft (typical of the full-scale system), surface settlements of 5 to 10 in. will likely occur.
- To increase the precision of the analysis for subsidence behavior, additional data are required to determine the properties of in-situ and fused materials. Field demonstration of the new ISV technique should consider soils tests (gradation testing, in-situ density measurements, and Maximum-Minimum Density tests) and should monitor subsurface deformations during subsidence and settlement (e.g., settlement markers, vertical extensometers, horizontal inclinometers).
- The relationship between the magnitude of maximum horizontal movement at the surface during subsidence and the maximum vertical subsidence indicates that horizontal movement should be minimal since vertical subsidence is minimal. However, to protect ISV equipment, the equipment should be designed so that the footings would be placed beyond the range of the predicted maximum horizontal movement.

Settlements greater than that predicted could occur for mechanisms not evaluated in this report. These additional mechanisms were not evaluated based on limited PNL experience indicating they were not credible. Further data is needed to determine if these additional mechanisms require analysis.

This report was prepared exclusively for PNL for specific application to a proposed ISV subsurface field test in sand and gravels at the Hanford site. The evaluation was performed in accordance with generally accepted geotechnical practices and analyses. It is recommended that contingencies be included in the planning of an ISV field test. Aspects related to subsidence should have a geotechnical review performed. Demonstration of the new ISV technique for other soil types will require further analysis.

3.0 Subsidence Analyses

The reduction in porosity from ISV results in a volume decrease for the vitrified soils. Subsidence is visible when the process is initiated at the soil surface and has been observed, at engineering-scale, to create a void when started in the soil subsurface (Tixier, Stottlemire, and Murphy 1991; Luey and Seiler 1995). At field-scale, movement of in-situ materials into the void space could cause surface settlements that adversely affect the ISV process and equipment. The magnitude and location of these settlements must be determined so that future ISV equipment can be adequately designed to preclude such event effects.

Figure 3.1 illustrates a potential pilot-scale geometry for initiating the ISV process in the soil subsurface. Initiation of the ISV process in the subsurface requires that ISV starter material be placed between an array of electrodes. The geometry shown in Figure 3.1 would be created using directional drilling techniques to create linear paths that connect diagonally opposed electrodes. A planar path between the electrodes is also a potential means for initiating the ISV process (Luey and Seiler 1994). Two subsidence scenarios have been identified for the geometry in Figure 3.1. This section evaluates the implications of these scenarios, including the effect of parameter uncertainties as well as uncertainties in the underlying mechanisms.

3.1 Assumptions And Material Properties

3.1.1 Assumed Pilot-Scale Geometry

The ISV melt was assumed to be approximately cylindrical in shape with the melt initiated at a depth of 15 ft and progressing downward to a depth of 25 ft. A downward melt rate of approximately one inch per hour was used. The off-gas hood above the process area was assumed to be octagonal with a radius of 7 ft. In the calculations, a range of geometries for the ISV system was considered to determine differences between pilot-scale and larger scale systems. ISV melt radii of 5, 10, 15, and 20 ft were considered for initiation depths of 10, 15, and 25 ft. In all cases, the soil zone was 10 ft thick.

3.1.2 Assumed Material Properties

Based on GAI observations, the primary geologic unit underlying PNL's test site is the Hanford formation. The Hanford formation soils are classified as GP (poorly graded gravels) according to ASTM D 2487 (1993), with 22% cobbles, 28% gravels, 20% medium to coarse sand, 25% fine sand, and <5% fines (New Jersey Institute of Technology 1995). Figure 3.2 shows the results of a particle size distribution analysis performed by PNL specifically for this study; the results are consistent with those reported by New Jersey Institute of Technology (1995). The soil profile analyzed in this report considers the following (Figure 3.1):

- in-situ soils (sand and gravel) above the vitrification zone

Figure 3.1. Schematic of Potential ISV Pilot-Scale Test Configuration

Coarse	Fine	C	Med	Fine	FINES (Silt or Clay)
GRAVEL		SAND			

SAMPLE ID	DEPTH	W%	LL	PL	PI	USCS	DESCRIPTION
ISV-1						SP	m-f SAND and c-f GRAVEL, trace fines, (SP).

(after PNL, 1994)

Figure 3.2. Particle Size Distribution for PNL's ISV Test Site Soils

- in-situ soils in a thin zone, located approximately 2 in. to 2 ft from the ISV melt, that may have been thermally altered slightly, resulting in a small increased cohesive strength
- fused in-situ soils immediately adjacent to the melt; in previous tests this zone has been about 2 in. thick and composed of fused sand and gravel fragments
- fused ISV melt itself.

Material properties for the soils at PNL's test site were based primarily on the grading curve shown in Figure 3.2 and on previous GAI experience with Hanford gravels. The range of material properties for these materials was derived based on GAI's previous Hanford experience and on a literature review (e.g., Pfeider 1972; Lambe and Whitman 1969; WPPSS 1974; Fang 1991; Clarke 1966; Vutukuri, Lama, and Saluja 1974; GAI 1981).

Although GAI has completed numerous projects at the Hanford Site, the most extensive geo-technical testing of Hanford gravels is summarized in work GAI performed in conjunction with several nuclear power siting studies during the 1980s (GAI 1981). The assumed material properties are summarized in Table 3.1.

Table 3.1. Soil Material Properties for ISV Subsidence Analysis

<u>Property</u>	<u>Minimum</u>	<u>Most Likely</u>	<u>Maximum</u>	<u>Basis</u>
Friction Angle, In-Situ Soil	36	38	40	GAI 1981 Judgement
Cohesion, In-Situ Soil (psf)	0	25	100	GAI 1981 Judgement
Maximum Dry Density (pcf)	130	135	140	GAI 1981 Winkerton and Fang 1975 Judgement
Minimum % of Maximum Dry Density	85	87.5	90	GAI 1981 Winkerton and Fang 1975 Judgement
In-Situ Relative Density (%)	40	50	60	GAI 1981 Judgement
Maximum Available Bulking Factor, B_{max} (%)	@NA	6.7	@NA	Calculated from other parameters
Tensile Strength, Fused Soil, Obsidian (psf)	40,000	100,000	200,000	Vutukuri et al. 1974 Clarke 1966 Farmer 1968

Table 3.1. (contd)

<u>Property</u>	<u>Minimum</u>	<u>Most Likely</u>	<u>Maximum</u>	<u>Basis</u>
Poisson's Ratio, Fused Soil, Obsidian	0.25	0.25	0.3	Clarke 1966
Compressive Strength, Fused Soil, Obsidian (psf)	5×10^5	2×10^6	1×10^7	Vutukuri et al. 1974 Clarke 1966 Farmer 1968
Compressive Strength, Altered In-Situ Soil (psf)	5,000	7,500	15,000	Winkerton and Fang 1975 (based on cohesion and friction angle)
Average Porosity, ISV Melt (%)	3	5	14	Buelt et al. 1987
Angle of Draw (°)	30	45	60	Golder and MacLaren 1976
Young's Modulus, Fused Soil (psf)	2×10^5	5×10^5	1×10^6	Clarke 1966
Young's Modulus, Altered Soil (psf)	1×10^8	5×10^8	1×10^9	Clarke 1966
Effective Bulking Factor, C_p (%)	20	40	60	Judgement
Effective Bulking, B_{eff} (%)	@NA	2.7	@NA	Calculated using B_{max} and C_p

Comments regarding several of these properties are included below:

- **Friction Angle, In Situ Soil** describes the shear strength of in-situ soils above the ISV melt and is used to estimate the resistance of these material to movement into the ISV melt and the void space created above the melt. The friction angle was estimated primarily on the basis of values reported for similar soils at the Hanford 300W Area (GAI 1981).
- **Cohesion, In-Situ Soil** describes the cohesive (stress independent) component of strength of in-situ soils above the ISV melt. These values were estimated based on values reported for similar soils at the Hanford 300W Area (GAI 1981) and on engineering judgment.

- **Relative Density, In-Situ Soil** describes the unit weight of in-situ soils in terms of relative density compared to the Maximum and Minimum laboratory values. These values were estimated based on values reported for similar soils at the Hanford 300W Area (GAI 1981) and on engineering judgement.
- **Tensile Strength, Fused Soil (Obsidian)** describes the strength of the ≈ 2 -in.-thick zone of fused soils surrounding the ISV melt for failures in tension. The values are estimated primarily from values reported for boric anhydride glass (Clarke 1966). The ranges were estimated from values reported for similar materials by Farmer (1968) and Vutukuri, Lama, and Saluja (1974).
- **Compressive Strength, Fused Soil (Obsidian)** describes the strength of the approximately 2-in. thick zone of fused soils surrounding the ISV melt for failures in compression. The values are estimated primarily from values reported for obsidian (Vutukuri, Lama, and Saluja 1974). The ranges were estimated from values reported for similar materials by Farmer (1968) and Clarke (1966).
- **Young's Modulus, Fused Soil** describes the stress necessary to produce a unit strain. The values are estimated primarily from that reported for boric anhydride glass (Clarke 1966).
- **Young's Modulus, Altered Soil** describes the stress necessary for unit strain in thermally altered soils. These values were derived primarily from engineering judgment with reference to values for cemented soils.
- **Compressive Strength, Altered Soil** describes the increased compressive strength in the approximately 2-ft-thick zone of altered soils surrounding the ISV melt. These values were derived from cohesion and friction angles from the literature, selected based on engineering judgement since actual data for similarly affected soils were unavailable.
- **Average Porosity, ISV melt** describes the void volume remaining in the fused soils following vitrification. Average porosity is used to estimate the volume of void space produced by the vitrification process. These values are estimated from the density values for the final ISV product reported by Buelt et al. (1987).
- **Angle of Draw** describes the angle of the cone of soils that are disturbed by the underground void formed during ISV. The angle of draw is defined as the angle between the horizontal and the cone of subsidence. This angle depends primarily on the geometry of the underground cavity, the depth of cover, and the friction angle of the in-situ materials. Values in the literature are reported primarily for tunnels rather than for cylindrical cavities. Golder and MacLaren (1976) present data on subsidence troughs above tunnels in cohesionless materials. The angles of draw for these near surface tunnels range from 23° to 50° , with a mean of 38° . Brauner (1973) reports a range from 45° to 65° above mined caverns, with a few values as low as 35° . Thus, the angle of draw appears to be 10° to 15° higher for deep caverns when compared to shallow tunnels. The ISV condition is, in effect, a shallow tunnel cavern, so the angle of draw should lie between the shallow tunnel and deep cavern values. The angle of draw was therefore estimated as between 30° and 60° with a mean of 45° .
- **Maximum Available Bulking Factor** describes the maximum percent increase in volume that can be achieved when a material at its in-situ density is bulked to its minimum relative density. This factor was derived based on Maximum and Minimum density values reported for materials with similar grading curves (Fang 1991) combined with assumed in-situ relative density ranging from 40% to 60%.
- **Effective Bulking Factor** is an empirical constant developed for this study to describe the average percentage of the maximum bulking factor that is achieved in raveling and disturbance of the soils above the ISV melt. This value depends on the degree of soil disturbance above the

ISV melt, the nature of soil placement in the void created by the ISV process, and the percentage of raveling materials that fuse into the ISV melt (decreasing in volume). The value significantly affects the result of the analysis. However, because of a lack of data, this value was estimated based on engineering judgment. The value is multiplied by the Maximum Available Bulking Factor to calculate the average effective bulking factor in the zone of interest.

Porosity of the in-situ soil describes the percentage of void spaces in the in-situ soil as a percentage of soil volume. Values used in the analysis were calculated from the assumed in-situ densities using a Specific Gravity of 2.65.

3.2 Subsidence Scenarios Evaluated

The possible subsidence behavior was modeled based on the following two related scenarios:

1. **Structural Bridging Of Void:** The ISV process produces void space at depth, which increases as the melt grows. Unless the overlying soil and thin fused soil zone have adequate strength, the roof of the developing void will collapse with the soil raveling into the void space. An evaluation was performed of this failure mechanism.
2. **Raveling And Bulking:** Assuming that the overlying soils have inadequate strength, the roof will collapse with the overlying soils raveling into the void as shown on Figure 3.3. The subsidence model consisted of the following assumed sequence:
 - A portion of the collapsing soils may come into contact with high temperature melt materials. This may melt the raveling soils, which would join the fused mass and further increase the volume of the void. Based on the engineering judgement of PNL's ISV staff and observations made by Luey and Seiler (1995) during an engineering-scale test initiated in the subsurface, it is likely that only a small portion of the initially raveled soil would actually melt. This opinion is based on the fact that the active melt zone is moving downward at approximately one inch per hour, and the raveling soils will likely form a thermal barrier that will minimize upward growth of the melt.
 - Once the thermal barrier forms, soils that break off and fall ("raveling") into the growing void decrease in density as they are transformed from the in-situ condition to their bulked or loosened condition.
 - The decrease in soil density due to raveling cause a decrease in the void volume. Any void volume unaccounted for due to bulking would propagate to the surface, forming a subsidence trough with the shape of a normal distribution.

Schematic Not to Scale

Figure 3.3. Raveling and Bulking Schematic for ISV Subsidence Analysis (not to scale)

3.2.1 Scenario 1: Structural Bridging of Void

3.2.1.1 General Discussion

Based on engineering judgment, it was considered unlikely that the overlying soil and thin fused soil zone would have adequate strength to bridge the void. Thus, rather than complete a sophisticated analysis, a cursory analysis based on several simplifying assumptions was made to assess the likelihood that bridging would occur. The approach consisted of two models:

- arching model to estimate stresses on the roof of the void
- structural analysis to compute the factor of safety of a failure occurring in the fused and altered zones. The main failure mode is tensile stress in the fused zone.

The analysis and results are summarized in the Appendix. In essence, the analysis indicated that the two-inch-thick fused zone is too thin to support the roof of the void except for very small melt radii less than about 1 to 2 ft. Such melt radii are similar to those for ISV engineering-scale tests. The presence of void spaces at completion of an engineering-scale test (Luey and Seiler 1995) is supported by this analysis. With a melt radius greater than 5 ft, effective bridging will not likely occur.

3.2.1.2 Structural Lining Behavior

The two-inch-thick fused zone is expected to completely surround the ISV melt. Theoretically, if the melt were spherical in shape, the fused zone would act as an outer structural "tunnel lining." This configuration would have considerable strength, since a structural liner would act as a ring in compression. The compressive stress on such a spherical liner could be calculated as (Obert and Duvall 1967),

$$\sigma_c = K_r \gamma_s H R_1 / t_f \quad (1)$$

where K_r is an empirical constant [approximately 0.6, Obert and Duvall (1967)] and t_f is the effective fused zone thickness. The factor of safety, F_s , for failure of a structural liner in compression is then the ratio of the compressive strength, S_c , to the compressive stress,

$$F_s = S_c / \sigma_c \quad (2)$$

The compressive strength of obsidian is approximately 2 M psf (Vutukuri, Lama, and Saluja 1974). The results for a variety of assumptions imply that the 2-in.-thick fused zone could fully support the overlying stresses and effectively eliminate any subsidence potential.

However, this scenario is unlikely because the melt is not spherical and areas of tension forces will likely develop, resulting in the type of failure described in Section 3.2.1.1 above. In addition, as shown in Figure 3.1, the roof of the void is penetrated by the ISV electrode array, further weakening the fused zone above the ISV melt.

3.2.2 Scenario 2: Raveling and Bulking

3.2.2.1 General Discussion

Calculation of the subsidence due to the void space created by ISV is developed in this section. The calculation consists of determining the volume of the void, determining the volume of bulking available to fill the void, and propagation of this displacement to the surface. In addition to a conventional deterministic evaluation, a probabilistic evaluation was also completed.

3.2.2.2 Estimate of the Volume of the ISV Void

The void created by the ISV process would be equal to the in situ volume of the soils before vitrification, V_s , multiplied by the difference between the in-situ porosity, n_0 , and the porosity following vitrification, n_v ,

$$\begin{aligned} V_s &= V_v + V_m \\ V_v &= V_s (n_0 - n_v) / (1 - n_v) \end{aligned} \quad (3)$$

where V_v is the volume of the void space created by the ISV process and V_m is the volume of vitrified material. For a cylindrical soil volume of height T_s , the relationship between the volume of the void and the radius, R_1 , of the ISV soil volume is:

$$\begin{aligned} V_s &= \pi R_1^2 T_s \\ V_v &= \pi R_1^2 T_s (n_0 - n_v) / (1 - n_v) \end{aligned} \quad (4)$$

The average height of the void, D_v , can be calculated by dividing the volume of the void by the area, A_v , as follows:

$$\begin{aligned} D_v &= V_v / A_v \\ D_v &= V_v / (\pi R_1^2) \\ D_v &= T_s (n_0 - n_v) / (1 - n_v) \end{aligned} \quad (5)$$

Given a soil volume height, T_s , of 10 ft, an assumed in-situ porosity of 22%, and an ISV melt porosity of 5% based on most likely values in Table 3.1, the average void height, D_v , is about 2 ft. This value provides a practical upper bound estimate on average settlement, although a somewhat higher upper bound could be obtained considering melting of raveled materials from above the ISV void.

3.2.2.3 Bulking Analysis - Maximum Available Bulking

After calculation of the volume of the ISV void, the next calculation required is the volume increase in the materials above the ISV void. Bulking is well documented in tunneling (Golder and MacLaren 1976), underground mining (Pfleider 1972), and subsidence prediction (NCB 1975). The magnitude of bulking depends on the relative density of the in-situ materials and the nature of their in-situ and disturbed structures.

A range of maximum and minimum densities for soils are reported in Fang (1991). Of the 56 soils reported by Fang, six were selected as the most similar to the gradation curve for the PNL test site soils. The average maximum-minimum densities for the six soils selected was about 137 pcf (maximum) and 115 pcf (minimum). A Maximum-Minimum Density test was completed for another GAI project at the Hanford Site on the Hanford gravels indicated a maximum density of 135 pcf and a minimum density of 120 pcf.

The maximum available bulking percentage, B_{max} , depends on the in-situ density, γ_0 , and the minimum density, γ_{min} . The maximum available bulking percentage can be calculated as follows:

$$B_{max} = \frac{\gamma_0 - \gamma_{min}}{\gamma_{min}} \quad (6)$$

Using the most likely values shown in Table 3.1, the computed B_{max} value was 6.7%.

3.2.2.4 Bulking Analysis - Average Effective Bulking

The actual bulking behavior is likely to be relatively complex as the melt grows and soil ravel or bulks into the void. The initial raveled soil may melt and be incorporated into the melt, producing in effect a negative bulking factor. Soil that initially ravel into the void and does not melt may bulk to the minimum density. As the melt continues and a zone of loosened soil develops above the melt, there will likely be a transition from soil at a minimum density at the top of the melt to soil at the in-situ density at the top of the bulked zone. The effective bulking is defined as the average bulking factor in the disturbed zone affected by the melt. Theoretically, the effective bulking can be obtained by integrating the change in density within the disturbed zone from the in-situ density, $\gamma_0(z)$, to the disturbed in-situ density, $\gamma_B(z)$:

$$B_{\text{eff}} = B_{\text{max}} \int_{z = \text{void}}^{\text{Surface}} \frac{\gamma_0(z) - \gamma_B(z)}{\gamma_0(z)} dz \quad (7)$$

There is no information on the likely distribution of density following disturbance. In addition, the likelihood and extent of raveling soils fusing into the melt and increasing in density is unknown. In order to account for these effects, the analysis related effective bulking to the maximum available bulking by an empirical proportionality constant, C_b ,

$$B_{\text{eff}} = C_b B_{\text{max}} \quad (8)$$

C_b is referred to as the "effective bulking factor." A value of C_b of 1.0 would result if all soils within the disturbed zone bulked from the in-situ density to the minimum density. A value of C_b of 0 would result if the average density of the disturbed soils was the same after disturbance as before disturbance, as a result of the compensating effects of bulking and density increase due to fusing in the zone near the melt.

The volume of bulking, V_b , can be calculated as the volume of disturbed materials, V_d , multiplied by the effective bulking B_{eff} . The volume of disturbed materials is generally estimated using the "angle of draw" B (Brauner 1973). The angle of draw is the angle of the cone of disturbed materials and is generally significantly shallower than the "angle of break," α , along which shear resistance is mobilized.

The volume of the disturbed materials can be estimated from the angle of draw B as shown in Figure 3.4. R_2 is the radius of the subsiding area at the surface.

$$V_b = B_{\text{eff}} V_d$$

$$V_b = \frac{B_{\text{max}} C_b H \pi}{3} (R_1^2 + R_2^2 + R_1 R_2) \quad (9)$$

$$R_2 = \tan(90 - B) \left(H + \frac{R_1}{\tan(90 - B)} \right)$$

The volume of the subsidence trough V_s can be estimated from the volume of the underground void minus the bulking volume, assuming that the bulking completely fills the void.

$$V_s = V_v - V_b \quad (10)$$

a. Volume of Disturbed Zone

b. Volume of Settlement through Surface Subsidence Radius R_2

Figure 3.4. Schematic for Estimating Volume of Draw

The volume of the ISV void was estimated assuming a cylindrical melt. Figure 3.5 shows the average subsidence for a range of effective bulking factors, B_{eff} , assuming a decrease in porosity for the ISV melt of about 17% based on the most likely values shown in Table 3.1. For most values of angle of draw and effective bulking factors, the average subsidence and total volume of subsidence would be zero. For a typical combination ($R_1 = 5'$, $H = 15'$, $B = 45^\circ$), an effective bulking factor of less than 2% would be sufficient to prevent the appearance of settlement at the surface.

3.2.2.5 Maximum Subsidence

The average value of subsidence, δ_{av} , can be calculated by dividing the volume of subsidence by the area over which subsidence occurs,

$$\delta_{av} = \frac{V_s}{\pi R_2^2} \quad (11)$$

However, it is more useful to calculate the maximum subsidence (i.e., at the center) and the subsidence at the edge of the ISV off-gas hood.

The shape of the surface settlement troughs is well established to usually take the form of a normal distribution (see Obert and Duvall 1967; Pfeider 1972; Brauner 1973). The maximum subsidence can therefore be calculated from the volume of the subsidence trough and the angle of draw (Figure 3.4b). A normally shaped subsidence trough is shown in Figure 3.6 and is defined by

$$\delta(r) = \delta_{max} e^{-r^2 / (2\sigma^2)} \quad (12)$$

where σ is the distance from the point of maximum subsidence to the point of inflection in the subsidence profile (Golder and MacLaren 1976). The radial distance sigma can be estimated from a relationship from Obert and Duvall (1967)

$$\sigma \approx \frac{R_2}{2} \quad (13)$$

Assumptions

In Situ Porosity 22%

ISV Melt Porosity 5%

Depth 15'

Angle of Draw 45°

Average subsidence calculated as
trough volume divided by trough
area (radius = R_2 , see text)

Figure 3.5. Average Subsidence for Range of Effective Bulking Factors and ISV Void Radii

After Obert and Duvall, 1967

Figure 3.6. Idealized Representation of Trough Subsidence (after Obert and Duvall 1987)

The maximum subsidence, $\delta_{\max}$, can be found by integrating the area under the subsidence curve to the total subsidence, V_s

$$\begin{aligned}
 V_s &= \int_0^{2\pi} \int_0^{\infty} \delta(x) \, dr \, d\theta \\
 V_s &= 2\pi \delta_{\max} \int_0^{\infty} e^{-r^2/(2\sigma^2)} \, dr \\
 \delta_{\max} &= \frac{V_s}{2\pi \int_0^{\infty} e^{-r^2/(2\sigma^2)} \, dr} = \frac{V_s}{2\pi\sigma^2}
 \end{aligned} \tag{14}$$

Figure 3.7 shows the maximum settlement, $\delta_{\max}$, for a range of initial in-situ porosities, angles of draw, and effective bulking factors. The porosity of the ISV melt is assumed to be 5%. The settlement $\delta(r)$ at any point at the surface can then be calculated using equation 12. Given an angle of draw of 45° , an effective bulking factor of 2.7%, an initial in-situ porosity of 22%, a melt radius of 5 ft, and a melt depth of 15 ft, the maximum subsidence is calculated to be zero. These are considered the most likely values. It was necessary to use either a very low effective bulking factor or an unrealistically high angle of draw to produce any surface subsidence at a melt radius of 5 ft. At a radius of 10 ft, the most likely values indicated a surface subsidence of about 2.5 in.

3.2.2.6 Probabilistic Analysis

In order to obtain a probabilistic estimate of subsidence, a range of material properties were simulated using the Monte Carlo method within an Excel 4.0/Crystal Ball 3.0 model. Appendix B presents the results for a number of Monte Carlo model simulation runs. This model made the following assumptions:

- The dominate mechanism is bulking with limited meting of the initial raveling soil; the probabilistic analysis does not consider the case of significant melting of the ravelled soils, which would result in much larger settlement values.
- The material properties were described by triangular distributions of properties, using the values in Table 3.1. The properties simulated using stochastic properties were angle of draw, maximum available bulking ($B_{\max}$), effective bulking factor (C_b), in-situ soil porosity, and the average porosity of the ISV melt.
- The settlement trough volume is calculated as the volume of the ISV void less the volume of bulking, as described in Section 3.2.2.4.
- The shape of the settlement trough is normal as described in Section 3.2.2.5.

Because of the likely volume of bulking, the probability of subsidence was low for an ISV pilot-scale application with a melt radius of 5 ft and an initiation depth of 15 ft. However, for a melt radius of 10 or 15 ft (typical dimensions for a full-scale ISV melt), the likelihood of subsidence increases significantly. Table 3.2 summarizes the results of several geometries and probability values. At a depth of 15 ft, the expected maximum settlement (50th percentile value) for a melt radius of 5 ft was zero. For the 95th percentile value, the maximum subsidence was about 0.75 in. At a melt radius of 10 ft, the results increased to about 1.8 in. (50th percentile) and 6 in. (95th percentile). At a melt radius of 15 ft, the results increased to about 5 in. (50th percentile) and 10 in. (95th percentile).

a. Maximum Subsidence, ISV Melt Radius = 5 feet

b. Maximum Subsidence, ISV Melt Radius = 10 feet

Assumptions

In Situ Porosity 22%
 ISV Melt Porosity 5%
 Depth 15'

Figure 3.7. Subsidence at Trough Center

c. Maximum Subsidence, ISV Melt Radius = 5 feet

d. Maximum Subsidence, ISV Melt Radius = 10 feet

Subsidence (inches)

14-15	6-7
13-14	5-6
12-13	4-5
11-12	3-4
10-11	2-3
9-10	1-2
8-9	0-1
7-8	

Assumption:

ISV Melt Porosity 5%

Depth 15'

Angle of Draw 45°

Figure 3.7. (contd)

Table 3.2. Results of Probabilistic Analysis

<u>Case</u>	<u>Surface Subsidence in Inches</u>			
	<u>50%</u>	<u>75%</u>	<u>90%</u>	<u>95%</u>
<u>Maximum</u>				
Melt Radius in Feet				
2.5	0.00	0.00	0.00	0.00
5	0.00	0.00	0.26	0.78
10	1.81	3.36	4.93	5.90
15	5.02	7.04	9.00	10.22
<u>At Hood Footings</u>				
Melt Radius in Feet				
5	0.00	0.00	0.19	0.55
<u>Average</u>				
Melt Radius in Feet				
2.5	0.00	0.00	0.00	0.00
5	0.00	0.00	0.13	0.36
10	0.90	1.68	2.46	2.96
15	2.51	3.52	4.50	5.11

Notes:

1. See Appendix B for specific results.
2. Percentages represent the likelihood that the actual subsidence values will be less than the stated values.
3. Results assume insignificant melting of collapsing soils.

3.3 Horizontal Movements

Horizontal movements during subsidence are near their maximum at the location of the proposed footings as shown in Figure 3.6. The magnitude of maximum horizontal movement at the surface during subsidence is generally in the range of 0.16 to 0.45 times the maximum vertical subsidence (Brauner 1973). According to Brauner, maximum horizontal displacement, HOR_{max} , can be estimated as

$$HOR_{max} = \frac{R_1 \ln 2}{2H} \delta_{max} \quad (15)$$

However, since vertical subsidence is not expected to be significant, horizontal movements are also not expected to be significant. For ISV applications, the off-gas hood should be of sufficient size, such as to extend beyond the footings shown in Figure 3.6, to allow for a margin of safety.

4.0 References

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Appendix A

Failure of Fused Zone And Overlying Soils

Appendix A

Failure of Fused Zone And Overlying Soils

This appendix presents a simplified structural analysis carried out to determine the stability of fused and altered soil layers above the void created by in situ vitrification. This analysis is based on the methods used for evaluating subsidence above mined areas (see e.g., Obert and Duvall 1967). The analysis combines calculation of stresses on the fused and altered layers based on arching theory with a strength analysis based on elasticity theory (Timoshenko and Goodier 1934) and composite material theory (MacGregor 1988). Strength analyses are presented for both the fused layer itself and for the combination of the fused and altered layers.

A.1 Strength Analysis Of Fused Zone

The stiffness of the 2-in.-thick fused layer is expected to be several orders of magnitude greater than that for the altered zone. As a result, stress will concentrate within the fused zone, and the altered zone is expected to increase stability primarily through stress redistribution in compression. Therefore, the first strength analysis carried out reflects only the strength of the fused zone.

The strength of the fused zone is analyzed as follows: Timoshenko and Goodier (1934) analyzed the stresses on a circular disk supported at its edges, Figure A.1. They calculated the radial tensile stress, σ_r , on this zone using the Equation (A.1),

$$\sigma_r = \frac{3(3 + \nu)}{32} \left(\frac{R_1^2 z}{t^3} \right) q \quad (\text{A.1})$$

where t is one half the thickness of the fused zone, z is the depth of the point of consideration beneath the center of the fused zone, R_1 is the radius of the fused zone, ν is Poisson's ratio, and q is the stress due to overlying materials.

a. Failure of Fused Zone under overburden weight.

b. Failure of Fused Zone with Arching

Figure A.1. Stress On Fused Soil

The maximum radial tensile stress, and therefore the initiation of failure, would occur at the bottom center of the disk,

$$\sigma_r = \frac{3(3 + \nu)}{32} \left(\frac{R_1^2 q}{t^2} \right) \quad (\text{A.2})$$

The stability of the 2-in.-thick fused zone can be calculated using a factor of safety, defined as the ratio of the tensile strength of the material, $S_{\max}$, to the radial tensile stress, σ_r . For the purposes of this analysis, the tensile strength will be estimated as 100,000 psf. The factor of safety then depends on the vertical stress q applied to the disk:

$$F_s = S_{\max} / \sigma_r \quad (\text{A.3})$$

A.2 Strength Analysis, Fused Zone And Altered Zones

The approximately 2-in.-thick fused soils layer and the approximately 2-ft-thick altered soil layer could contribute to the support of the overlying soils. The combined strength of the two material can be calculated using "transformed section" approaches developed for analysis of composite materials such as steel-reinforced concrete. In this approach, the material strength is analyzed in a transformed geometry in which the sections are scaled to account for their varying stiffness (MacGregor 1988). This analysis is illustrated in Figure A.2.

Until failure occurs, the composite material (fused plus altered soils) is assumed to be linearly-elastic. The fundamental assumption of linear-elastic bending theory is that strains are linearly distributed over the depth of each member. When a beam consisting of materials with different elastic moduli is loaded, this leads to a different stress distribution because the stiffer material accepts more stress for a given strain. In order to carry out elastic analyses, a transformed section is created consisting of a single material with a constant elastic modulus. To maintain the correct stiffness, the area of the transformed material is adjusted by the ratio,

$$R_t = R \left(\frac{E_a}{E_f} \right) \quad (\text{A.4})$$

where E_a and E_f are the elastic moduli of the altered and fused soils, respectively, and R and R_t are the ISV melt radius and the transformed radius for the altered soils, respectively.

a. Analysed Geometry

b. Transformed Geometry

c. Transformed Section

Figure A.2. Composite Analysis Of Fused And Altered Zone

The location of the neutral (centroid axis) within the transformed composite material, z_{crit} , can then be calculated from the ratio of the first moment of the transformed section, Q_t , to the area of the transformed section, A_t ,

$$z_{crit} = \frac{Q_t}{A_t} \quad (A.5)$$

where z_{crit} is measured from the top of the altered material. The moment and the area are calculated from the respective thickness of the fused and altered soils t_f and t_a , and the radii of the fused and altered soils, R and R_t ,

$$\begin{aligned} A_t &= A_{at} + A_f \\ A_{at} &= 2R_t t_a \\ A_f &= 2R t_f \end{aligned} \quad (A.6)$$

$$\begin{aligned} Q_t &= A_{at} \frac{t_a}{2} + A_f \left(t_a + \frac{t_f}{2} \right) \\ Q_t &= R_t t_a^2 + R t_f (2t_a + t_f) \end{aligned} \quad (A.7)$$

Combining Equations (A.5) through (A.7), the location of the centroidal axis can be expressed as

$$z_{crit} = \frac{R_t t_a^2 + R t_f (2t_a + t_f)}{2(R_t t_a + R t_f)} \quad (A.8)$$

The average stress, σ_{Rav} , on the transformed section at the location of failure (i.e., the bottom of the fused layer) can be calculated from the Equation,

$$\sigma_{Rav} = \frac{M_t z_c}{I_t} \quad (A.9)$$

where I_t is the moment of inertia of the transformed section, M_t is the moment applied to the transformed section, and z_c is the centroidal distance from the bottom of the layer.

The moment of inertia I_t on the transformed section is calculated as,

$$I_t = A_{at}(z_{crit} - \frac{t_a}{2})^2 + A_f(\frac{t_f}{2} + t_a - z_{crit})^2 + 2(\frac{R_t t_a^3 + R_t t_f^3}{12}) \quad (A.10)$$

The moment on the transformed section at location of failure, M_t , can then be derived from movement equilibrium of the simply-supported disk of altered and fused soils, assuming that the overburden stress q is applied at the top of the section,

$$M_t = q \frac{R^3}{3} \quad (A.11)$$

The centroidal distance from the bottom of the transformed section z_c is the distance of

$$z_c = t_a + t_f - z_{crit} \quad (A.12)$$

The average tensile stress σ_{Rav} on the transformed section at the extreme bottom fiber can be expressed by combining Equations (A.9) through (A.12).

The failure stress σ_R for the composite material will be the stress at the center of the section, and for linear elastic material, it may be related to the average stress σ_{Rav} through Poisson's ratio, as

$$\sigma_R = \sigma_{Rav} \left[6 \frac{(3 + \nu)}{16} \right] \quad (A.13)$$

Since the altered soil will contribute part of the overburden weight, loading the combined section, Equation (A.11) is valid for overburden thickness significantly greater than the thickness of the altered soil zone. The load provided by the altered zone can be approximated using the principle of superposition,

$$\sigma_{Rav}(\text{total}) = \sigma_{Rav}(q, t_a) + \sum_{i=1}^4 3 \sigma_{Rav}(q(i), t_a i / 4) \quad (A.14)$$

where $\sigma_{Rav}(\text{total})$ is the total stress on the failure plane, $\sigma_{Rav}(q, t_a)$ is the stress on the failure plane due to overburden applied at the top of the altered soil zone, and $\sigma_{Rav}(q(i), t_a i / 4)$ is the stress due

to the weight of the soil in the i 'th slice of altered soil. Note that the transformed section is different for each slice of altered soil.

This approximation will be used to estimate the factor of safety using Equation (A.2) with the stress at failure defined by Equation (A.13).

A.3 Stress Applied To Fused And Altered Soil Layers

The stress q on the fused zone at failure was estimated using two alternative assumptions for the mode of failure.

- 1) Until deformation occurs above the ISV melt, the weight of a vertical column of soil to the surface must be supported directly by the strength of the 2-in.-thick fused soil ("obsidian") at the top of the melt.
- 2) Once deformation begins, the horizontal stresses within the soil above the melt increase, providing a soil strength to support the overlying support and supporting a portion of the overlying soils through an arching mechanism.

A.3.1 Simple Stress Estimate

With no movement in the overlying materials, the stress q due to the overlying materials can be estimated as

$$q = \gamma H \quad (A.15)$$

This is the simplest assumption and should be considered overly conservative, because arching, described in the next section, generally limits the maximum soil load on a tunnel to approximately 2 to 3 times the tunnel radius. For a cavern, which has a three-dimensional geometry, the soil load should be even smaller.

A.3.2 Arching Stress Estimate

With slight movement of the overlying materials, arching occurs, reducing the net stress on the 2-in.-thick fused zone by transferring the weight of these material through horizontal stresses.

$$q \approx \gamma R_1 a$$

$$a \approx \frac{1}{K \tan \phi} (1 - e^{-K(R_1 / H) \tan \phi}) \quad (A.16)$$

The factors "K" and "a" above were introduced to account for the effect of arching. In an underground tunnel beneath cohesive soils, the maximum stress on the tunnel is defined by a soil column 2 to 2.5 times the tunnel radius, not the total soil column to the surface. K represents the horizontal stress above the tunnel as a percentage of the geostatic stress γH . The factor a represents the effect of arching.

For deep tunnels or caverns, the arching stress should be increased to include a component of load on the soil arch from overlying soils. However, the above equation is appropriate for the range of depth-to-cavern radius being considered for ISV.

A.4 Results Of Analysis

The factor of safety for two overburden stress levels with and without arching are plotted for the failure in the fused soils alone in Figures A.3a and A.3b, and for the composite strength of fused and altered soils in Figures A.4a and A.4b. These factors of safety were calculated using the maximum likelihood values of tensile strength for fused soils, 100,000 psf. For the simple analysis at a depth of 15 ft, a factor of safety of 1 (failure) is reached for a radius of approximately 1.5 ft for the fused soils alone, and a radius of 2.5 ft for the fused and altered soils. For the analysis including arching, a factor of safety of 1 is reached for a radius of approximately 3 ft for the fused soils alone and 4.5 ft for the fused and altered soils.

An Excel/Crystal Ball stochastic simulation was carried out to calculate the probability of failure, based on an assumption of arching with $K = 1.0$. This analysis assumed triangular distributions for friction angle and maximum tensile strength for the fused soil with minimum and maximum likelihood, and maximum values.

For the analysis with strength provided solely by the fused soils, the probability of failure is less than 1% for melt radii less than 2 ft. The probability of failure is approximately 50% for a melt radius of 2.5 ft. The probability of failure exceeds 99% for all ISV melt radius greater than 4 ft.

For the analysis with strength provided solely by the composite of altered and fused soils, the probability of failure is less than 1% for melt radii less than 3 ft. The probability of failure is approximately 50% for a melt radius of 4 ft. The probability of failure exceeds 99% for all ISV melt radius greater than 5 ft.

a. Failure of Fused Zone - No Displacement

b. Failure of Fused Zone With Arching

Figure A.3. Failure Of Fused Zone

a. Failure of Fused and Altered Zones - No Displacement

b. Failure of Fused and Altered Zones with Arching

Figure A.4. Failure Of Composite Fused And Altered Zones

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Appendix B

Monte Carlo Simulations

Forecast: Avg. Subsidence, R=5ft

Cell: F24

Summary:

Display Range is from 0 to 0.045 ft

Entire Range is from 0.000000033387247316 to 0.1498029515393173 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00011998164651324

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.004096484
Median (approx.)	0.000288609
Mode (approx.)	0.000749048
Standard Deviation	0.013940608
Variance	0.000194341
Skewness	4.409392747
Kurtosis	25.31464429
Coeff. of Variability	3.403066532
Range Minimum	3.33872E-08
Range Maximum	0.149802952
Range Width	0.149802918
Mean Std. Error	0.000119982

Forecast: Avg. Subsidence, R=5ft (cont'd)

Cell: F24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.33872E-08
5%	2.8891E-05
25%	0.000144321
50%	0.000288609
75%	0.000432897
95%	0.032374108
100%	0.149802952

End of Forecast

Forecast: Avg. Subsidence, R=10 ft

Cell: G24

Summary:

Display Range is from 0 to 0.35 ft

Entire Range is from 0.00000002496755177 to 0.50431966435092768 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000698864041943592

Statistics:

	Value
Trials	13500
Mean	0.089934427
Median (approx.)	0.075398308
Mode (approx.)	0.002521623
Standard Deviation	0.081200664
Variance	0.006593548
Skewness	0.892427659
Kurtosis	3.383018188
Coeff. of Variability	0.902887431
Range Minimum	2.49676E-08
Range Maximum	0.504319664
Range Width	0.504319639
Mean Std. Error	0.000698864

Forecast: Avg. Subsidence, R=10 ft (cont'd)

Cell: G24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	2.49676E-08
5%	0.00044155
25%	0.017729039
50%	0.075398308
75%	0.140196279
95%	0.246156039
100%	0.504319664

End of Forecast

Forecast: Avg. Subsidence, R=15 ft

Cell: H24

Summary:

Display Range is from 0 to 0.55 ft

Entire Range is from 0.00000001920699933 to 0.70054127909439556 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001016717064956812

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.216711248
Median (approx.)	0.208784666
Mode (approx.)	0.003502726
Standard Deviation	0.118131848
Variance	0.013955133
Skewness	0.393813862
Kurtosis	2.896721457
Coeff. of Variability	0.54511175
Range Minimum	1.9207E-08
Range Maximum	0.700541279
Range Width	0.70054126
Mean Std. Error	0.001016717

Forecast: Avg. Subsidence, R=15 ft (cont'd)

Cell: H24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	1.9207E-08
5%	0.03078924
25%	0.131069915
50%	0.208784666
75%	0.29349544
95%	0.425995823
100%	0.700541279

End of Forecast

Forecast: Max. Subsidence, R=5 ft

Cell: F26

Summary:

Display Range is from 0 to 0.09 ft

Entire Range is from 0.000000066774494632 to 0.29960590307863461 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00023996329302648

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.008192968
Median (approx.)	0.000577218
Mode (approx.)	0.001498096
Standard Deviation	0.027881215
Variance	0.000777362
Skewness	4.409392747
Kurtosis	25.31464429
Coeff. of Variability	3.403066532
Range Minimum	6.67745E-08
Range Maximum	0.299605903
Range Width	0.299605836
Mean Std. Error	0.000239963

Forecast: Max. Subsidence, R=5 ft (cont'd)

Cell: F26

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	6.67745E-08
5%	5.77819E-05
25%	0.000288643
50%	0.000577218
75%	0.000865794
95%	0.064748217
100%	0.299605903

End of Forecast

Forecast: Max Subsidence, R=10 ft

Cell: G26

Summary:

Display Range is from 0 to 0.7 ft

Entire Range is from 0.000000049935103541 to 1.00863932870185535 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001397728083887184

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.179868854
Median (approx.)	0.150796615
Mode (approx.)	0.005043246
Standard Deviation	0.162401328
Variance	0.026374191
Skewness	0.892427659
Kurtosis	3.383018188
Coeff. of Variability	0.902887431
Range Minimum	4.99351E-08
Range Maximum	1.008639329
Range Width	1.008639279
Mean Std. Error	0.001397728

Forecast: Max Subsidence, R=10 ft (cont'd)

Cell: G26

Percentiles:

Percentile
0%
5%
25%
50%
75%
95%
100%

ft (approx.)
4.99351E-08
0.0008831
0.035458079
0.150796615
0.280392558
0.492312079
1.008639329

End of Forecast

Forecast: Max Subsidence, R=15 ft

Cell: H26

Summary:

Display Range is from 0 to 1.1 ft

Entire Range is from 0.000000038413998659 to 1.40108255818879113 ft

After 13,500 Trials, the Std. Error of the Mean is 0.002033434129913625

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.433422497
Median (approx.)	0.417569332
Mode (approx.)	0.007005451
Standard Deviation	0.236263696
Variance	0.055820534
Skewness	0.393813862
Kurtosis	2.896721457
Coeff. of Variability	0.54511175
Range Minimum	3.8414E-08
Range Maximum	1.401082558
Range Width	1.40108252
Mean Std. Error	0.002033434

Forecast: Max Subsidence, R=15 ft (cont'd)

Cell: H26

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.8414E-08
5%	0.06157848
25%	0.262139831
50%	0.417569332
75%	0.586990879
95%	0.851991647
100%	1.401082558

End of Forecast

Forecast: Footing Subsidence, R=5 ft

Cell: F27

Summary:

Display Range is from 0 to 0.055 ft

Entire Range is from 0.000000060251643046 to 0.18124377384150667 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000162029820129344

Statistics:

	Value
Trials	13500
Mean	0.005643829
Median (approx.)	0.000349382
Mode (approx.)	0.000906279
Standard Deviation	0.018826164
Variance	0.000354424
Skewness	4.194770629
Kurtosis	22.69547018
Coeff. of Variability	3.335707838
Range Minimum	6.02516E-08
Range Maximum	0.181243774
Range Width	0.181243714
Mean Std. Error	0.00016203

Cell: F27

Forecast: Footing Subsidence, R=5 ft (cont'd)

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	6.02516E-08
5%	3.49924E-05
25%	0.000174721
50%	0.000349382
75%	0.000524043
95%	0.045822189
100%	0.181243774

End of Forecast

Forecast: Footing Subsidence, R=10 ft

Cell: G27

Summary:

Display Range is from 0 to 0.5 ft

Entire Range is from 0.000000046240457277 to 0.76820281545647207 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001127318996269674.

Statistics:

	Value
Trials	13500
Mean	0.149370454
Median (approx.)	0.129297108
Mode (approx.)	0.00384106
Standard Deviation	0.130982631
Variance	0.01715645
Skewness	0.770266382
Kurtosis	3.03446386
Coeff. of Variability	0.876897857
Range Minimum	4.62405E-08
Range Maximum	0.768202815
Range Width	0.768202769
Mean Std. Error	0.001127319

Forecast: Footing Subsidence, R=10 ft (cont'd)

Cell: G27

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	4.62405E-08
5%	0.000674434
25%	0.031044942
50%	0.129297108
75%	0.23393608
95%	0.397258007
100%	0.768202815

End of Forecast

Forecast: Footing Subsidence, R=15 ft

Cell: H27

Summary:

Display Range is from 0 to 1 ft

Entire Range is from 0.000000036208293143 to 1.200189041121692 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001755849394228685

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.384779742
Median (approx.)	0.374986924
Mode (approx.)	0.006000981
Standard Deviation	0.204011264
Variance	0.041620596
Skewness	0.308604159
Kurtosis	2.794243673
Coeff. of Variability	0.530202714
Range Minimum	3.62083E-08
Range Maximum	1.200189041
Range Width	1.200189005
Mean Std. Error	0.001755849

Forecast: Footing Subsidence, R=15 ft (cont'd)

Cell: H27

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.62083E-08
5%	0.056542274
25%	0.237340783
50%	0.374986924
75%	0.520487799
95%	0.737793643
100%	1.200189041

End of Forecast

Forecast: Delta Porosity

Cell: F21

Summary:

Display Range is from 0.075 to 0.25

Entire Range is from 0.070967095040170569 to 0.24159833608565162

After 13,500 Trials, the Std. Error of the Mean is 0.000236249199190257

Statistics:	Value
Trials	13500
Mean	0.16468121
Median (approx.)	0.167472187
Mode (approx.)	0.170786371
Standard Deviation	0.027449676
Variance	0.000753485
Skewness	-0.330193059
Kurtosis	2.636078232
Coeff. of Variability	0.166683718
Range Minimum	0.070967095
Range Maximum	0.241598336
Range Width	0.170631241
Mean Std. Error	0.000236249

Forecast: Delta Porosity (cont'd)

Cell: F21

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.070967095
5%	0.116082808
25%	0.145697795
50%	0.167472187
75%	0.185090664
95%	0.205752849
100%	0.241598336

End of Forecast

Forecast: In Situ Density

Cell: F14

Summary:

Display Range is from 120 to 132

Entire Range is from 119.055440996836623 to 132.668151340263819

After 13,500 Trials, the Std. Error of the Mean is 0.018775710800563678

Statistics:

	<u>Value</u>
Trials	13500
Mean	125.9751723
Median (approx.)	125.9875902
Mode (approx.)	126.0659868
Standard Deviation	2.181540457
Variance	4.759118767
Skewness	0.005701619
Kurtosis	2.619062263
Coeff. of Variability	0.017317225
Range Minimum	119.055441
Range Maximum	132.6681513
Range Width	13.61271034
Mean Std. Error	0.018775711

Forecast: In Situ Density (cont'd)

Cell: F14

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	119.055441
5%	122.3784197
25%	124.4357818
50%	125.9875902
75%	127.5164264
95%	129.6171756
100%	132.6681513

End of Forecast

Forecast: Average Subsidence, R=2.5

Cell: 124

Summary:

Display Range is from 0 to 0.00035 ft

Entire Range is from 0.000000039768765966 to 0.011504095756045938 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00000114791228453

Statistics:

	Value
Trials	13500
Mean	1.86026E-06
Median (approx.)	1.92175E-05
Mode (approx.)	5.756E-05
Standard Deviation	0.000133375
Variance	1.7789E-08
Skewness	80.90988053
Kurtosis	6639.33845
Coeff. of Variability	71.69697231
Range Minimum	3.97688E-08
Range Maximum	0.011504096
Range Width	0.011504056
Mean Std. Error	1.14791E-06

Forecast: Average Subsidence, R=2.5 (cont'd)

Cell: 124

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.97688E-08
5%	1.95754E-06
25%	9.62861E-06
50%	1.92175E-05
75%	2.88063E-05
95%	3.64774E-05
100%	0.011504096

End of Forecast

Forecast: Maximum Subsidence, R=2.5

Cell: I26

Summary:

Display Range is from 0 to 0.0007 ft

Entire Range is from 0.000000079537531932 to 0.023008191512091877 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000002295824569061

Statistics:

	Value
Trials	13500
Mean	3.72053E-06
Median (approx.)	3.84349E-05
Mode (approx.)	0.00011512
Standard Deviation	0.000266751
Variance	7.11559E-08
Skewness	80.90988053
Kurtosis	6639.33845
Coeff. of Variability	71.69697231
Range Minimum	7.95375E-08
Range Maximum	0.023008192
Range Width	0.023008112
Mean Std. Error	2.29582E-06

Forecast: Maximum Subsidence, R=2.5 (cont'd)

Cell: 126

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	7.95375E-08
5%	3.91508E-06
25%	1.92572E-05
50%	3.84349E-05
75%	5.76126E-05
95%	7.29548E-05
100%	0.023008192

End of Forecast

Summary:

Display Range is from 0 to 0.00035 ft

Entire Range is from 0.00000007037165064 to 0.011161343911771492 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000001128213047942

Statistics:

	<u>Value</u>
Trials	13500
Mean	1.88364E-06
Median (approx.)	1.86766E-05
Mode (approx.)	5.58767E-05
Standard Deviation	0.000131087
Variance	1.71837E-08
Skewness	80.42672349
Kurtosis	6562.759049
Coeff. of Variability	69.59211009
Range Minimum	7.03717E-08
Range Maximum	0.011161344
Range Width	0.011161274
Mean Std. Error	1.12821E-06

Forecast: Footing Subsidence, R=2.5 (cont'd)

Cell: 127

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	7.03717E-08
5%	1.931E-06
25%	9.3735E-06
50%	1.86766E-05
75%	2.79798E-05
95%	3.54223E-05
100%	0.011161344

End of Forecast

Forecast: Avg. Subsidence, R=5ft

Cell: F24

Summary:

Display Range is from 0 to 0.045 ft

Entire Range is from 0.000000033387247316 to 0.1498029515393173 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00011998164651324

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.004096484
Median (approx.)	0.000288609
Mode (approx.)	0.000749048
Standard Deviation	0.013940608
Variance	0.000194341
Skewness	4.409392747
Kurtosis	25.31464429
Coeff. of Variability	3.403066532
Range Minimum	3.33872E-08
Range Maximum	0.149802952
Range Width	0.149802918
Mean Std. Error	0.000119982

Forecast: Avg. Subsidence, R=5ft (cont'd)

Cell: F24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.33872E-08
10%	5.77486E-05
25%	0.000144321
50%	0.000288609
75%	0.000432897
90%	0.010890468
100%	0.149802952

End of Forecast

Forecast: Avg. Subsidence, R=10 ft

Cell: G24

Summary:

Display Range is from 0 to 0.35 ft

Entire Range is from 0.00000002496755177 to 0.50431966435092768 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000698864041943592

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.089934427
Median (approx.)	0.075398308
Mode (approx.)	0.002521623
Standard Deviation	0.081200664
Variance	0.006593548
Skewness	0.892427659
Kurtosis	3.383018188
Coeff. of Variability	0.902887431
Range Minimum	2.49676E-08
Range Maximum	0.504319664
Range Width	0.504319639
Mean Std. Error	0.000698864

Forecast: Avg. Subsidence, R=10 ft (cont'd)

Cell: G24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	2.49676E-08
10%	0.000883075
25%	0.017729039
50%	0.075398308
75%	0.140196279
90%	0.205362617
100%	0.504319664

End of Forecast

Forecast: Avg. Subsidence, R=15 ft

Cell: H24

Summary:

Display Range is from 0 to 0.55 ft

Entire Range is from 0.00000001920699933 to 0.70054127909439556 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001016717064956812

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.216711248
Median (approx.)	0.208784666
Mode (approx.)	0.003502726
Standard Deviation	0.118131848
Variance	0.013955133
Skewness	0.393813862
Kurtosis	2.896721457
Coeff. of Variability	0.54511175
Range Minimum	1.9207E-08
Range Maximum	0.700541279
Range Width	0.70054126
Mean Std. Error	0.001016717

Forecast: Avg. Subsidence, R=15 ft (cont'd)

Cell: H24

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	1.9207E-08
10%	0.067008314
25%	0.131069915
50%	0.208784666
75%	0.29349544
90%	0.375049053
100%	0.700541279

End of Forecast

Forecast: Max. Subsidence, R=5 ft

Cell: F26

Summary:

Display Range is from 0 to 0.09 ft

Entire Range is from 0.000000066774494632 to 0.29960590307863461 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00023996329302648

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.008192968
Median (approx.)	0.000577218
Mode (approx.)	0.001498096
Standard Deviation	0.027881215
Variance	0.000777362
Skewness	4.409392747
Kurtosis	25.31464429
Coeff. of Variability	3.403066532
Range Minimum	6.67745E-08
Range Maximum	0.299605903
Range Width	0.299605836
Mean Std. Error	0.000239963

Forecast: Max. Subsidence, R=5 ft (cont'd)

Cell: F26

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	6.67745E-08
10%	0.000115497
25%	0.000288643
50%	0.000577218
75%	0.000865794
90%	0.021780936
100%	0.299605903

End of Forecast

Forecast: Max Subsidence, R=10 ft

Cell: G26

Summary:

Display Range is from 0 to 0.7 ft

Entire Range is from 0.000000049935103541 to 1.00863932870185535 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001397728083887184

Statistics:

	Value
Trials	13500
Mean	0.179868854
Median (approx.)	0.150796615
Mode (approx.)	0.005043246
Standard Deviation	0.162401328
Variance	0.026374191
Skewness	0.892427659
Kurtosis	3.383018188
Coeff. of Variability	0.902887431
Range Minimum	4.99351E-08
Range Maximum	1.008639329
Range Width	1.008639279
Mean Std. Error	0.001397728

Forecast: Max Subsidence, R=10 ft (cont'd)

Cell: G26

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	4.99351E-08
10%	0.00176615
25%	0.035458079
50%	0.150796615
75%	0.280392558
90%	0.410725234
100%	1.008639329

End of Forecast

Forecast: Max Subsidence, R=15 ft

Cell: H26

Summary:

Display Range is from 0 to 1.1 ft

Entire Range is from 0.000000038413998659 to 1.40108255818879113 ft

After 13,500 Trials, the Std. Error of the Mean is 0.002033434129913625

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.433422497
Median (approx.)	0.417569332
Mode (approx.)	0.007005451
Standard Deviation	0.236263696
Variance	0.055820534
Skewness	0.393813862
Kurtosis	2.896721457
Coeff. of Variability	0.54511175
Range Minimum	3.8414E-08
Range Maximum	1.401082558
Range Width	1.40108252
Mean Std. Error	0.002033434

Forecast: Max Subsidence, R=15 ft (cont'd)

Cell: H26

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.8414E-08
10%	0.134016627
25%	0.262139831
50%	0.417569332
75%	0.586990879
90%	0.750098106
100%	1.401082558

End of Forecast

Forecast: Footing Subsidence, R=5 ft

Cell: F27

Summary:

Display Range is from 0 to 0.055 ft

Entire Range is from 0.000000060251643046 to 0.18124377384150667 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000162029820129344

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.005643829
Median (approx.)	0.000349382
Mode (approx.)	0.000906279
Standard Deviation	0.018826164
Variance	0.000354424
Skewness	4.194770629
Kurtosis	22.69547018
Coeff. of Variability	3.335707838
Range Minimum	6.02516E-08
Range Maximum	0.181243774
Range Width	0.181243714
Mean Std. Error	0.00016203

Forecast: Footing Subsidence, R=5 ft (cont'd)

Cell: F27

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	6.02516E-08
10%	6.99246E-05
25%	0.000174721
50%	0.000349382
75%	0.000524043
90%	0.015736618
100%	0.181243774

End of Forecast

Forecast: Footing Subsidence, R=10 ft

Cell: G27

Summary:

Display Range is from 0 to 0.5 ft

Entire Range is from 0.000000046240457277 to 0.76820281545647207 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001127318996269674

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.149370454
Median (approx.)	0.129297108
Mode (approx.)	0.00384106
Standard Deviation	0.130982631
Variance	0.01715645
Skewness	0.770266382
Kurtosis	3.03446386
Coeff. of Variability	0.876897857
Range Minimum	4.62405E-08
Range Maximum	0.768202815
Range Width	0.768202769
Mean Std. Error	0.001127319

Forecast: Footing Subsidence, R=10 ft (cont'd)

Cell: G27

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	4.62405E-08
10%	0.001348822
25%	0.031044942
50%	0.129297108
75%	0.23393608
90%	0.336071456
100%	0.768202815

End of Forecast

Forecast: Footing Subsidence, R=15 ft

Cell: H27

Summary:

Display Range is from 0 to 1 ft

Entire Range is from 0.000000036208293143 to 1.200189041121692 ft

After 13,500 Trials, the Std. Error of the Mean is 0.001755849394228685

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.384779742
Median (approx.)	0.374986924
Mode (approx.)	0.006000981
Standard Deviation	0.204011264
Variance	0.041620596
Skewness	0.308604159
Kurtosis	2.794243673
Coeff. of Variability	0.530202714
Range Minimum	3.62083E-08
Range Maximum	1.200189041
Range Width	1.200189005
Mean Std. Error	0.001755849

Forecast: Footing Subsidence, R=15 ft (cont'd)

Cell: H27

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.62083E-08
10%	0.121859227
25%	0.237340783
50%	0.374986924
75%	0.520487799
90%	0.656933678
100%	1.200189041

End of Forecast

Forecast: Delta Porosity

Cell: F21

Summary:

Display Range is from 0.075 to 0.25

Entire Range is from 0.070967095040170569 to 0.24159833608565162

After 13,500 Trials, the Std. Error of the Mean is 0.000236249199190257

Statistics:

	<u>Value</u>
Trials	13500
Mean	0.16468121
Median (approx.)	0.167472187
Mode (approx.)	0.170786371
Standard Deviation	0.027449676
Variance	0.000753485
Skewness	-0.330193059
Kurtosis	2.636078232
Coeff. of Variability	0.166683718
Range Minimum	0.070967095
Range Maximum	0.241598336
Range Width	0.170631241
Mean Std. Error	0.000236249

Forecast: Delta Porosity (cont'd)

Cell: F21

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.070967095
10%	0.126825679
25%	0.145697795
50%	0.167472187
75%	0.185090664
90%	0.198542386
100%	0.241598336

End of Forecast

Forecast: In Situ Density

Cell: F14

Summary:

Display Range is from 120 to 132

Entire Range is from 119.055440996836623 to 132.668151340263819

After 13,500 Trials, the Std. Error of the Mean is 0.018775710800563678

Statistics:

	Value
Trials	13500
Mean	125.9751723
Median (approx.)	125.9875902
Mode (approx.)	126.0659868
Standard Deviation	2.181540457
Variance	4.759118767
Skewness	0.005701619
Kurtosis	2.619062263
Coeff. of Variability	0.017317225
Range Minimum	119.055441
Range Maximum	132.6681513
Range Width	13.61271034
Mean Std. Error	0.018775711

Forecast: In Situ Density (cont'd)

Cell: F14

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	119.055441
10%	123.0792934
25%	124.4357818
50%	125.9875902
75%	127.5164264
90%	128.8339046
100%	132.6681513

End of Forecast

Forecast: Average Subsidence, R=2.5

Cell: I24

Summary:

Display Range is from 0 to 0.00035 ft

Entire Range is from 0.000000039768765966 to 0.011504095756045938 ft

After 13,500 Trials, the Std. Error of the Mean is 0.00000114791228453

Statistics:

	<u>Value</u>
Trials	13500
Mean	1.86026E-06
Median (approx.)	1.92175E-05
Mode (approx.)	5.756E-05
Standard Deviation	0.000133375
Variance	1.7789E-08
Skewness	80.90988053
Kurtosis	6639.33845
Coeff. of Variability	71.69697231
Range Minimum	3.97688E-08
Range Maximum	0.011504096
Range Width	0.011504056
Mean Std. Error	1.14791E-06

Forecast: Average Subsidence, R=2.5 (cont'd)

Cell: 124

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	3.97688E-08
10%	3.87531E-06
25%	9.62861E-06
50%	1.92175E-05
75%	2.88063E-05
90%	3.45596E-05
100%	0.011504096

End of Forecast

Forecast: Maximum Subsidence, R=2.5

Cell: I26

Summary:

Display Range is from 0 to 0.0007 ft

Entire Range is from 0.000000079537531932 to 0.023008191512091877 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000002295824569061

Statistics:

	Value
Trials	13500
Mean	3.72053E-06
Median (approx.)	3.84349E-05
Mode (approx.)	0.00011512
Standard Deviation	0.000266751
Variance	7.11559E-08
Skewness	80.90988053
Kurtosis	6639.33845
Coeff. of Variability	71.69697231
Range Minimum	7.95375E-08
Range Maximum	0.023008192
Range Width	0.023008112
Mean Std. Error	2.29582E-06

Forecast: Maximum Subsidence, R=2.5 (cont'd)

Cell: 126

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	7.95375E-08
10%	7.75061E-06
25%	1.92572E-05
50%	3.84349E-05
75%	5.76126E-05
90%	6.91192E-05
100%	0.023008192

End of Forecast

Summary:

Display Range is from 0 to 0.00035 ft

Entire Range is from 0.00000007037165064 to 0.011161343911771492 ft

After 13,500 Trials, the Std. Error of the Mean is 0.000001128213047942

Statistics:

	<u>Value</u>
Trials	13500
Mean	1.88364E-06
Median (approx.)	1.86766E-05
Mode (approx.)	5.58767E-05
Standard Deviation	0.000131087
Variance	1.71837E-08
Skewness	80.42672349
Kurtosis	6562.759049
Coeff. of Variability	69.59211009
Range Minimum	7.03717E-08
Range Maximum	0.011161344
Range Width	0.011161274
Mean Std. Error	1.12821E-06

Forecast: Footing Subsidence, R=2.5 (cont'd)

Cell: 127

Percentiles:

<u>Percentile</u>	<u>ft (approx.)</u>
0%	7.03717E-08
10%	3.79162E-06
25%	9.3735E-06
50%	1.86766E-05
75%	2.79798E-05
90%	3.35616E-05
100%	0.011161344

End of Forecast

Crystal Ball Report
Simulation started on 7/19/94 at 8:07:57
Simulation stopped on 7/19/94 at 8:57:15

Forecast: Factor of Safety, Radius = 5 ft

Cell: J40

Summary:

Display Range is from 0.05 to 0.28

Entire Range is from 0.05 to 0.27

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	<u>Value</u>
Trials	24500
Mean	0.15
Median (approx.)	0.15
Mode (approx.)	0.13
Standard Deviation	0.04
Variance	0.00
Skewness	0.24
Kurtosis	2.40
Coeff. of Variability	0.30
Range Minimum	0.05
Range Maximum	0.27
Range Width	0.22
Mean Std. Error	0.00

Forecast: Factor of Safety, Radius = 5 ft (cont'd)

Cell: J40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.05
10%	0.09
25%	0.12
50%	0.15
75%	0.18
90%	0.21
100%	0.27

End of Forecast

Forecast: Factor of Safety, R=1

Cell: G40

Summary:

Display Range is from 5.00 to 27.50

Entire Range is from 5.19 to 27.97

After 24,500 Trials, the Std. Error of the Mean is 0.03

Statistics:

	Value
Trials	24500
Mean	14.90
Median (approx.)	14.52
Mode (approx.)	13.73
Standard Deviation	4.36
Variance	19.04
Skewness	0.26
Kurtosis	2.45
Coeff. of Variability	0.29
Range Minimum	5.19
Range Maximum	27.97
Range Width	22.78
Mean Std. Error	0.03

Forecast: Factor of Safety, R= 1 (cont'd)

Cell: G40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	5.19
10%	9.30
25%	11.69
50%	14.52
75%	18.00
90%	21.05
100%	27.97

End of Forecast

Forecast: Factor of Safety, $R = 2.5$

Cell: H40

Summary:

Display Range is from 0.25 to 2.00

Entire Range is from 0.34 to 1.83

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	<u>Value</u>
Trials	24500
Mean	1.00
Median (approx.)	0.97
Mode (approx.)	0.90
Standard Deviation	0.29
Variance	0.08
Skewness	0.25
Kurtosis	2.43
Coeff. of Variability	0.29
Range Minimum	0.34
Range Maximum	1.83
Range Width	1.48
Mean Std. Error	0.00

Forecast: Factor of Safety, $R = 2.5$ (cont'd)

Cell: H40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.34
10%	0.62
25%	0.78
50%	0.97
75%	1.20
90%	1.40
100%	1.83

End of Forecast

Forecast: Factor of Safety, R=4 ft

Cell: I40

Summary:

Display Range is from 0.05 to 0.50

Entire Range is from 0.09 to 0.49

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	<u>Value</u>
Trials	24500
Mean	0.27
Median (approx.)	0.26
Mode (approx.)	0.25
Standard Deviation	0.08
Variance	0.01
Skewness	0.25
Kurtosis	2.44
Coeff. of Variability	0.29
Range Minimum	0.09
Range Maximum	0.49
Range Width	0.40
Mean Std. Error	0.00

Forecast: Factor of Safety, R=4 ft (cont'd)

Cell: 140

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.09
10%	0.17
25%	0.21
50%	0.26
75%	0.33
90%	0.38
100%	0.49

End of Forecast

Crystal Ball Report
Simulation started on 7/19/94 at 8:07:57
Simulation stopped on 7/19/94 at 8:57:15

Forecast: Factor of Safety, Radius=5 ft

Cell: J40

Summary:

Display Range is from 0.05 to 0.28

Entire Range is from 0.05 to 0.27

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	<u>Value</u>
Trials	24500
Mean	0.15
Median (approx.)	0.15
Mode (approx.)	0.13
Standard Deviation	0.04
Variance	0.00
Skewness	0.24
Kurtosis	2.40
Coeff. of Variability	0.30
Range Minimum	0.05
Range Maximum	0.27
Range Width	0.22
Mean Std. Error	0.00

Forecast: Factor of Safety, Radius = 5 ft (cont'd)

Cell: J40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.05
5%	0.08
25%	0.12
50%	0.15
75%	0.18
95%	0.23
100%	0.27

End of Forecast

Forecast: Factor of Safety, R= 1

Cell: G40

Summary:

Display Range is from 5.00 to 27.50

Entire Range is from 5.19 to 27.97

After 24,500 Trials, the Std. Error of the Mean is 0.03

Statistics:

	<u>Value</u>
Trials	24500
Mean	14.90
Median (approx.)	14.52
Mode (approx.)	13.73
Standard Deviation	4.36
Variance	19.04
Skewness	0.26
Kurtosis	2.45
Coeff. of Variability	0.29
Range Minimum	5.19
Range Maximum	27.97
Range Width	22.78
Mean Std. Error	0.03

Forecast: Factor of Safety, $R=1$ (cont'd)

Cell: G40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	5.19
5%	8.15
25%	11.69
50%	14.52
75%	18.00
95%	22.63
100%	27.97

End of Forecast

Forecast: Factor of Safety, R=2.5

Cell: H40

Summary:

Display Range is from 0.25 to 2.00

Entire Range is from 0.34 to 1.83

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	Value
Trials	24500
Mean	1.00
Median (approx.)	0.97
Mode (approx.)	0.90
Standard Deviation	0.29
Variance	0.08
Skewness	0.25
Kurtosis	2.43
Coeff. of Variability	0.29
Range Minimum	0.34
Range Maximum	1.83
Range Width	1.48
Mean Std. Error	0.00

Forecast: Factor of Safety, $R=2.5$ (cont'd)

Cell: H40

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.34
5%	0.54
25%	0.78
50%	0.97
75%	1.20
95%	1.51
100%	1.83

End of Forecast

Forecast: Factor of Safety, R=4 ft

Cell: 140

Summary:

Display Range is from 0.05 to 0.50

Entire Range is from 0.09 to 0.49

After 24,500 Trials, the Std. Error of the Mean is 0.00

Statistics:

	Value
Trials	24500
Mean	0.27
Median (approx.)	0.26
Mode (approx.)	0.25
Standard Deviation	0.08
Variance	0.01
Skewness	0.25
Kurtosis	2.44
Coeff. of Variability	0.29
Range Minimum	0.09
Range Maximum	0.49
Range Width	0.40
Mean Std. Error	0.00

Forecast: Factor of Safety, $R=4$ ft (cont'd)

Cell: 140

Percentiles:

<u>Percentile</u>	<u>Value (approx.)</u>
0%	0.09
5%	0.15
25%	0.21
50%	0.26
75%	0.33
95%	0.41
100%	0.49

End of Forecast

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