# Stochastic Response Surface Verification Examples

The Stochastic Response Surface method uses a small number of strategically selected computations to create a response surface of factor of safety (FS) values for various combinations of input parameters. It then *predicts* the factor of safety values for any combination of samples and provides an estimated probability of failure. Since an Overall Slope probabilistic analysis can take hours or days in 3D, this method is advantageous in significantly cutting down computation time.

Although many verification examples have shown it to agree well with Latin-Hypercube results, it cannot always guarantee a result that is identical. However, it will be able to give you a ballpark PF value. It is always recommended to run at least one Latin-Hypercube Overall Slope analysis overnight.

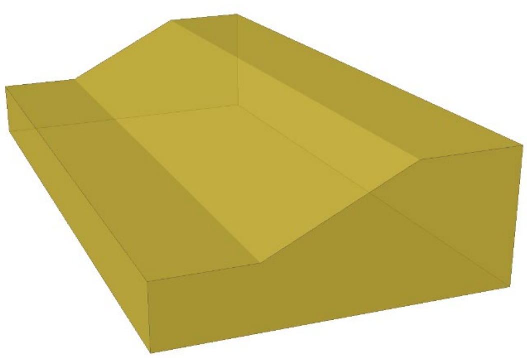
This document focuses on Overall Slope analyses through three complex examples. Global Minimum results, and all output data can be found in the accompanying spreadsheet.

## Example 1 Worst Case

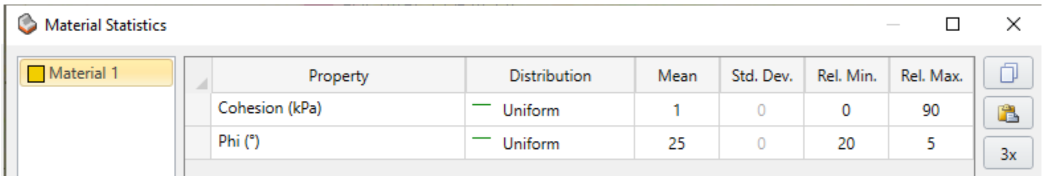
The first example uses a simple slope with two random variables. The random variables have a wide range of variability and uniform distributions, indicating all samples are equally likely.

An Overall Slope analysis with 100 samples was computed with both Latin-Hypercube and Response Surface. Response Surface required 20 computations.

**This example was constructed to show the worst case, where response surface has to capture cohesion ranging from 1 kPa to 91 kPa and friction angle ranging from 5 to 30 degrees, all with equal probability, in 20 samples. Furthermore, the use of 100 samples is likely not sufficient.**



| | |
|---|---|
| **Surface Type** | Sphere |
| **Search Method** | Particle Swarm Search |
| **Surface Altering Optimization** | Yes |
| **Method** | Janbu Simplified |
| **Deterministic FS (Janbu)** | 1.021 |



Material Statistics

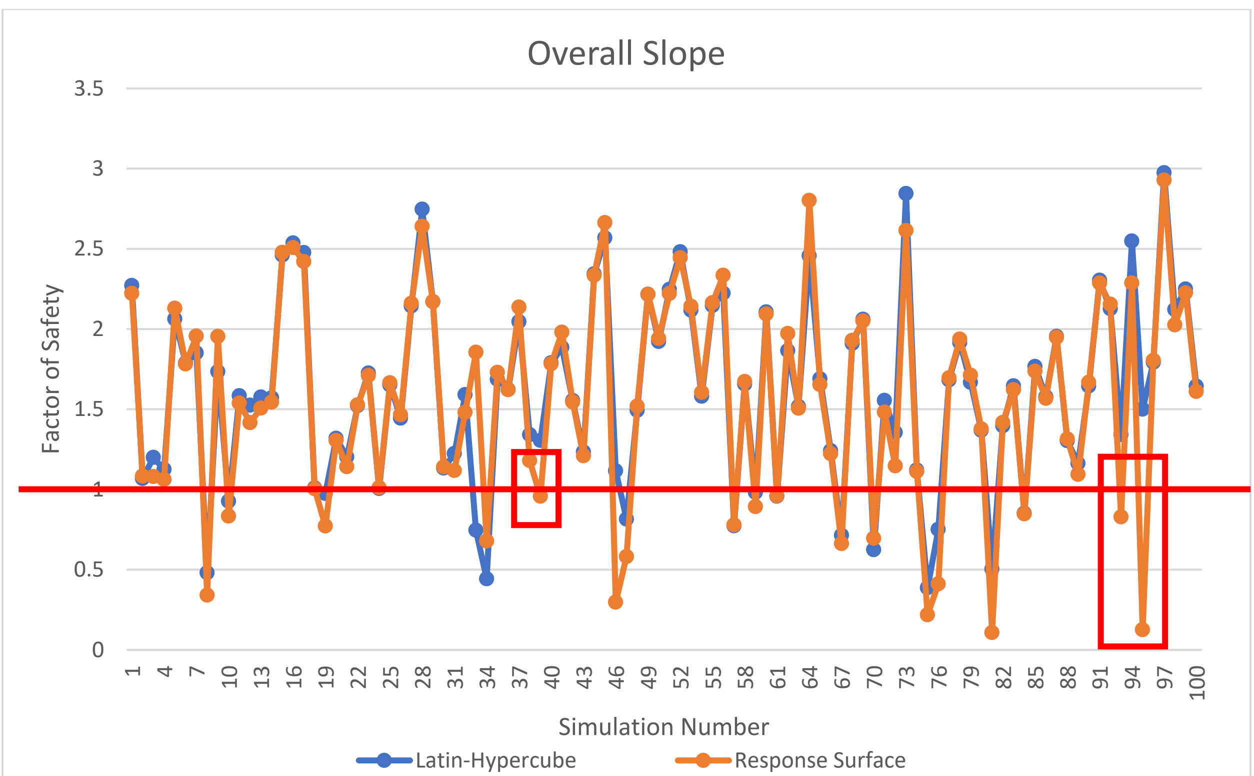
Material 1

| Property | Distribution | Mean | Std. Dev. | Rel. Min. | Rel. Max. |
|---|---|---|---|---|---|
| Cohesion (kPa) | Uniform | 1 | 0 | 0 | 90 |
| Phi (°) | Uniform | 25 | 0 | 20 | 5 |

The results are found below:

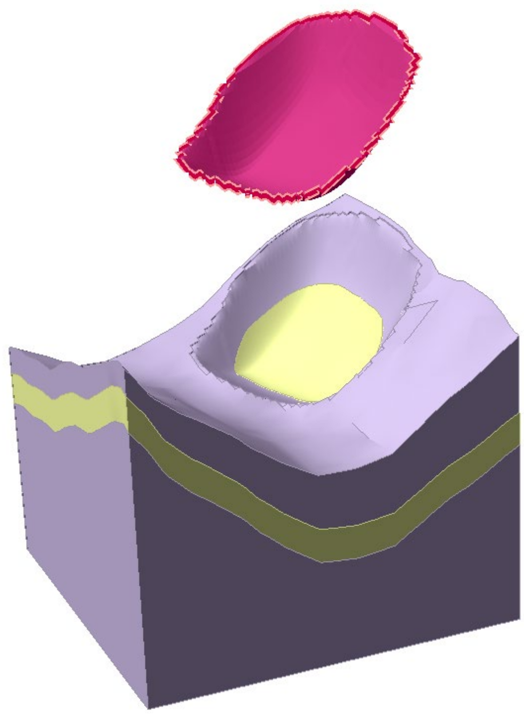
| Overall Slope | | | | |
|---|---|---|---|---|
| **Method** | **Num Samples** | **PF (%)** | **Mean FS** | **Time (min)** |
| Latin-Hypercube | 100 | 15.000 | 1.616 | 16.9 |
| Response Surface | 100 (20) | 18.000 | 1.575 | 3.8 |

Since only 100 samples were considered, this means that (18-15)*100 = 3 samples were found to be less than 1 with Response Surface, while greater than 1 with Latin-Hypercube. These three samples are easily spotted in the comparison plot below.

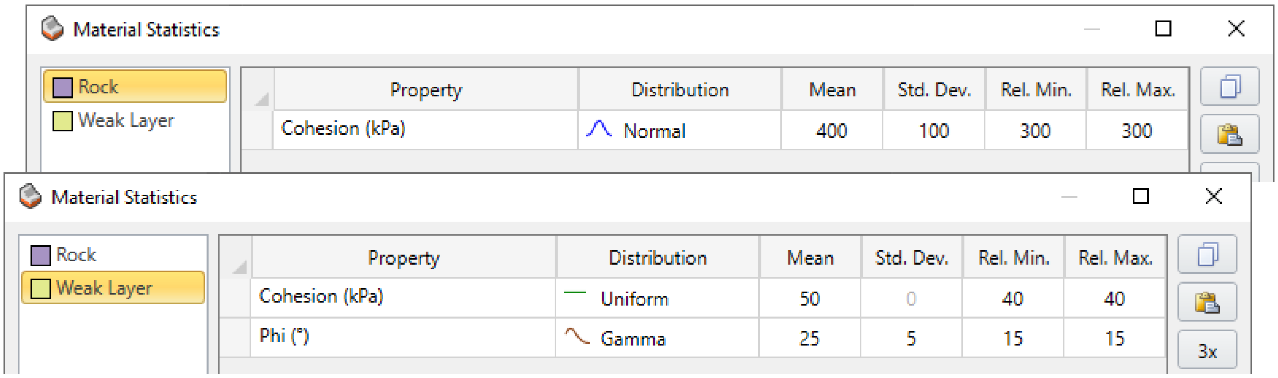


In short, this is a worst-case example where the range is very wide with a uniform distribution and the response surface must be created with 20 samples. Even so, the predictions are almost exact for most samples. Now we will move to more realistic examples.

### Example 2 Slope with Thin Weak Layer

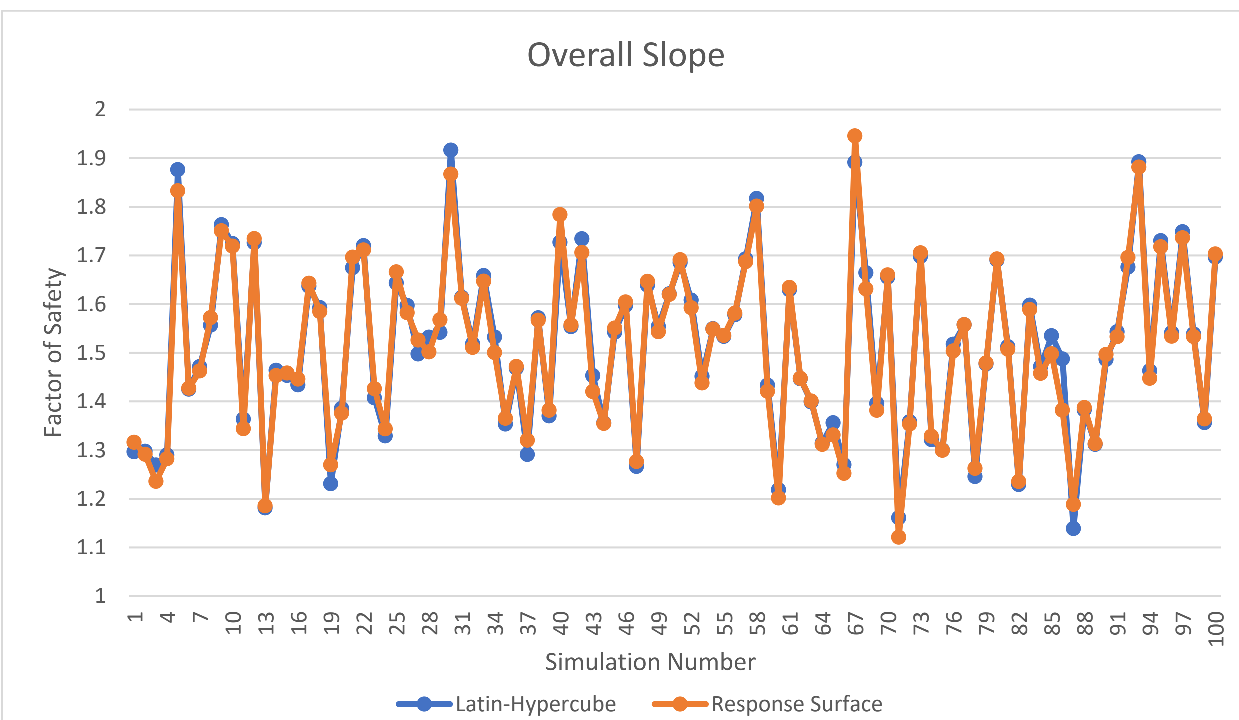


| | |
|---|---|
| **Surface Type** | Ellipsoid |
| **Search Method** | Particle Swarm Search |
| **Surface Altering Optimization** | Yes |
| **Method** | Bishop Simplified |
| **Deterministic FS (Bishop)** | 1.497 |



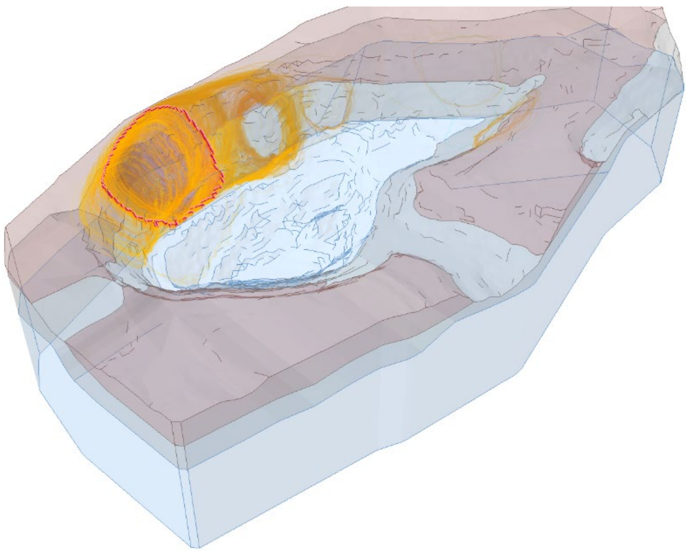

| Overall Slope | | | | |
|---|---|---|---|---|
| **Method** | **Num Samples** | **PF (%)** | **Mean FS** | **Time (hrs)** |
| Latin-Hypercube | 1000 | 0.300 | 1.488 | 17.3 |
| Response Surface | 1000 (40) | 0.200 | 1.484 | 0.5 |
| Latin-Hypercube | 40 | 0.000 | 1.481 | 0.5 |

The results indicate that with Latin-Hypercube 0.003*1000 = 3 samples were found to be below 1. With Response Surface, 0.002*1000 = 2 samples were found to be below 1. A look at the first 100 samples for both methods shows that they are in good agreement:



It is also notable that running only 40 Latin-Hypercube simulations on their own, is not enough to capture these failures (PF=0.0%).

## Example 3 Open Pit



| | |
|---|---|
| **Surface Type** | Ellipsoid |
| **Search Method** | Cuckoo Search |
| **Surface Altering Optimization** | Yes |
| **Method** | GLE/Morgenstern-Price |
| **Deterministic FS (GLE)** | 1.07 |

Material Statistics

Sandstone
Limestone
Ore

| Property | Distribution | Mean | Std. Dev. | Rel. Min. | Rel. Max. |
|---|---|---|---|---|---|
| Cohesion (kPa) | Normal | 460 | 100 | 300 | 300 |
| Phi (°) | Lognormal | 35 | 5 | 15 | 15 |

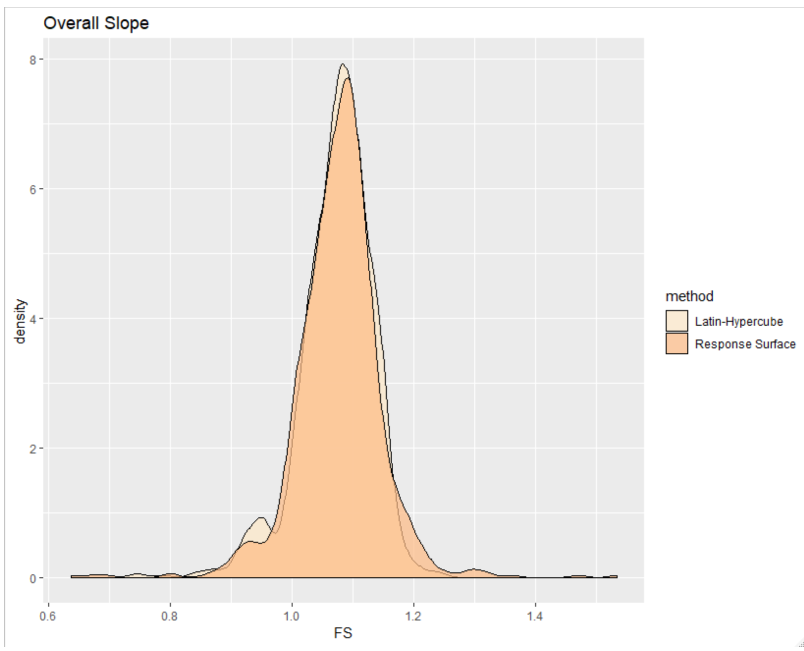
Material Statistics

Sandstone
Limestone
Ore

| Property | Distribution | Mean | Std. Dev. | Rel. Min. | Rel. Max. |
|---|---|---|---|---|---|
| Cohesion (kPa) | Normal | 280 | 75 | 225 | 225 |
| Phi (°) | Lognormal | 20 | 5 | 15 | 15 |

| Overall Slope - GLE | | | | |
|---|---|---|---|---|
| **Method** | **Num Samples** | **PF (%)** | **Mean FS** | **Time (hrs)** |
| Latin-Hypercube | 1000 | 8.400 | 1.074 | 25.0 |
| Response Surface | 1000 (70) | 8.600 | 1.077 | 1.3 |
| Latin-Hypercube | 70 | 10.000 | 1.074 | 1.3 |

The figure below shows the histogram of FS values found by Latin-Hypercube and Response Surface. The histograms are in good agreement. Of particular interest is the ability of Response Surface to recognize the other failure mode in the FS=0.95 region.




Finally, using the “Show All Surfaces” button allows us to see the original computations and surfaces that are used to train the Response Surface model for this example, and compare them to the surfaces found using Latin-Hypercube.