Frication Angle and Stability of Slopes
(T Cao, 6/8/2014)

Introduction
This write up addresses friction angle and slope stability issue raised by NRC staff in SER section 2.1.1.1.3.5.4 (Site Geotechnical Conditions and Stability of Subsurface Materials).

The applicant's estimation to determine shear strength parameters using relative density data as described in its soils engineering report, BSC Table I-17 (2002ab), indicated the value of the internal friction angle (shear strength) for the alluvium could be in the range of 33–52°, but the applicant described the shear strength of the alluvium using a value of 39°, which is in the middle between mean and the low end. The applicant stated in DOE Enclosure 1 (2009bg) the use of this value is appropriate and conservative because, at the scale of the ITS mat foundations, the geotechnical behavior of the alluvium has average characteristics over the very large volume of material.

However, the NRC staff has concerns on the limited scope of the geotechnical investigations to characterize shear strength of the alluvium, especially when the low end value 33° is used. The applicant provided a stability analysis in DOE Enclosure 1 (2009ej) that indicated 2:1 slopes in the alluvium will be stable under DBGM-2 seismic loading. The analysis considered shear strength on the basis of a friction angle of 39˚, but did not consider the effects of uncertainties in shear strength of the alluvium [e.g., a friction angle in the range of 33˚ through 52˚, as indicated in the soils engineering report, BSC Table I-17 (2002ab)].

In the following, the safety factors for slope stability in static and dynamic conditions are evaluated.

Safety Factor Calculations
To address this issue, we first calculated the safety factors using both friction angles 39° and 33°. Following the formulas on static stability in DOE Enclosure 1 (2009ej) the factor of safety for a slope in a cohesionless soil can be expressed:

$$FS = \tan(\phi) / \tan(\alpha)$$

where *FS* is the static factor of safety, ϕ is the angle of internal friction and α is the inclination of the slope. For two slopes with an inclination of 26.6° (i.e., 2H:1V slope) and internal friction angles of 39° and 33°, this equation yields two factors of safety for the slope of 1.62, and 1.30.

An estimate of the dynamic stability of the slope is obtained using a pseudostatic method in DOE Enclosure 1 (2009ej), where the effective increase in horizontal and vertical loads on the slope due to the dynamic loads is approximated using additional static loads applied to the slope. Following equations 2-5 of DOE Enclosure 1 (2009ej), we have factors of safety 1.2 and 0.6 for two slopes with internal friction angles of 39° and 33° respectively. The parameters used in this calculation are (1) the static safety factors 1.62 and 1.30, (2) the inclination angle of the slope 26.6°, (3) a weighting factor, which is described in the literature to vary from 0.1 to 0.5, depending on the source (Kramer 1996, p. 436) and the upper bound value 0.5 is used for conservativeness, (4) the DBGM-2 horizontal peak ground acceleration of 0.45 g, which is from the YM ground motion hazard curve (SAR Fig.

1.1-80) for probability of exceedance of 10^{-4} or the probability for Category 2 event sequences (see 10 CFR Part 63.2). The safety factors for the dynamic stability of the slope with internal friction angles of 39° and 33° are 1.2 and 0.6 respectively. The following table summarizes the above calculation results:

Friction Angle	Static FS	Dynamic FS
39°	1.62	1.30
33°	1.2	0.6

It seems obvious that safety factor is too low when the friction angle is at 33° and the staff's concern is valid. But let us do another analysis, which DOE and NRC staff didn't realized its advantage.

As shown in BSC (2002ab) Table 1-11 (Summary of and Statistics for Relative Density Results), the friction angle has a large uncertainty and follows a distribution with mean=68, median=71, stand deviation=21, maximum =120, and minimum=25. So we can get the cumulative density function (CDF) of this distribution and find that the probabilities for friction angle less and equal to 39° and less and equal to 33° are about 0.07 and 0.04 respectively. The probability for the DBGM-2 horizontal peak ground acceleration of 0.45 g is 10^{-4} (see attached SAR Fig. 1.1-80). The weighting factor (0.1 to 0.5) used above to get the low FS for dynamic slope stability is 0.5. If 0.3 is used, the dynamic slope FS will be 1.0. So from 0.1 to 0.5, only 1/3 of the chance the FS will be smaller than 1.0. We can include this factor into the calculation of the final probability for FS less than 1.0 when friction angle 33° is used, which is $0.04*(1/3)*10^{-4}$ = 1.3e-6. This is too low to be considered as category 2 events. For friction angle of 39° the probability is 2.3e-6, also showing not Category 2 events. We can find a higher PGA probability to make up the event probability qualifying for being Category 2 event. This PGA probability will be 7.5e-3 ($=10^{-4}/(0.04*1/3)$). But for such high probability, the PGA is only about 0.05 g, which will lead to safety factor nine (=0.45/0.05) times of 0.6, or 5.4. It is very safe.

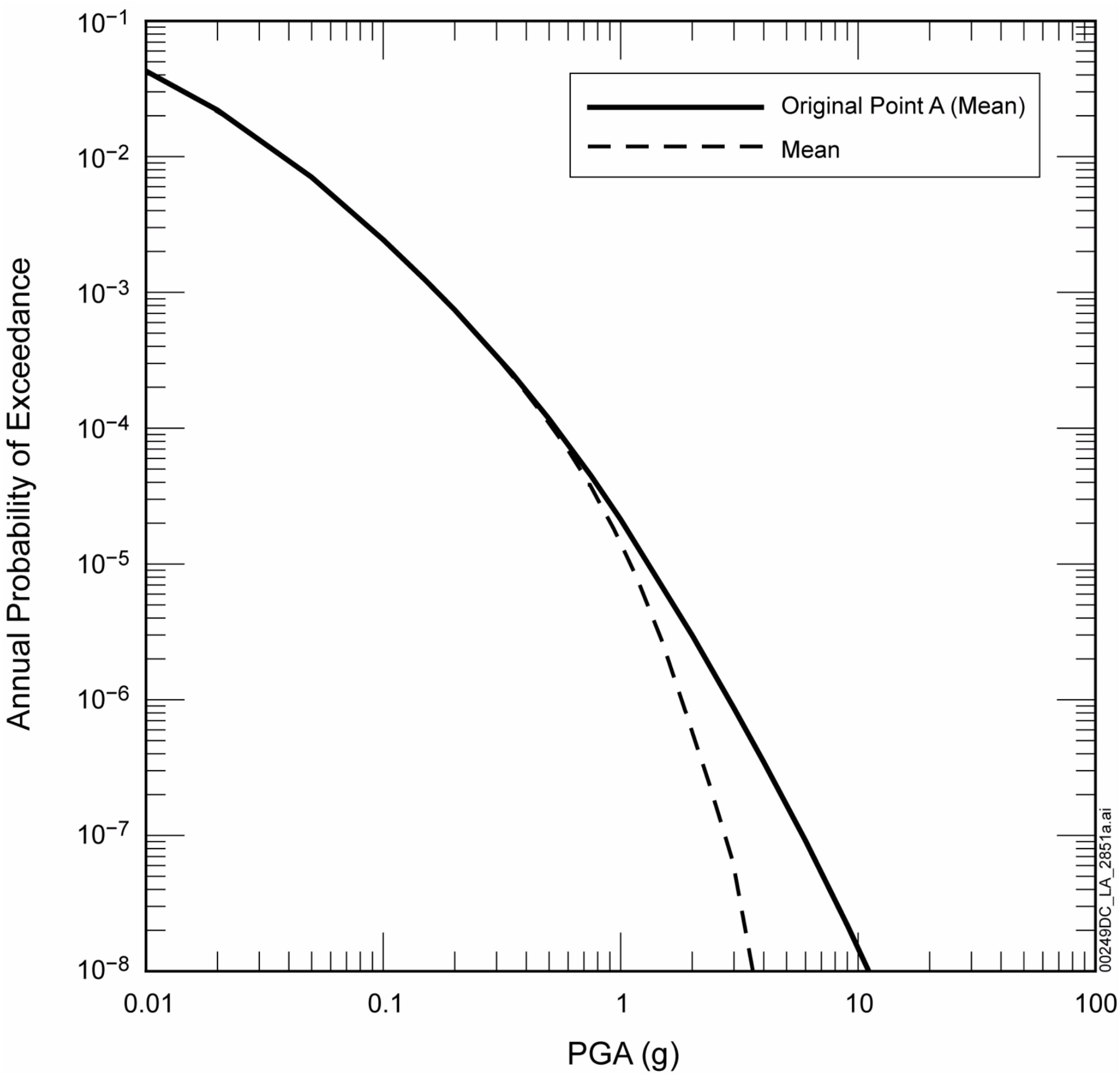

Figure 1.1-80.Conditioned and Unconditioned Reference Rock Outcrop Mean Horizontal Peak Ground Acceleration Hazard Curves (From SAR)

Conclusion

Because the events of slope stability under seismic shaking has probability much lower than Category 2 criterion (>10^{-4}) when the friction angle is as low as 33°, there is no need to be considered.

References

BSC. 2002ab. "Soils Report for North Portal Area, Yucca Mountain Project." 100–00C–WRP0–00100–000–000. Las Vegas, Nevada: Bechtel SAIC Company, LLC.

DOE. 2009ej. "Yucca Mountain—Supplemental Response to Request for Additional Information Regarding License Application (Safety Analysis Report Sections 1.1.10, 1.2.2, 1.1.5.2, and 1.1.5.3), Safety Evaluation Report Vol. 2, Chapter 2.1.1.1, Set 1." Letter (September 22) J.R. Williams to C. Jacobs (NRC). ML092650715. Washington, DC: DOE, Office of Technical Management.