Recommendation for the Lower Limit of the Waste Shear Strength (Parameter BOREHOLE : TAUFAIL) – 8097

C.G. Herrick, M. Riggins, E.D. Vugrin, and B.Y. Park
Sandia National Laboratories
4100 National Parks Highway, Carlsbad, NM 88220

ABSTRACT

The Waste Isolation Pilot Plant demonstrates compliance with federal containment requirements by means of performance assessment calculations carried out to estimate the probability and consequences of radionuclide releases from the repository to the accessible environment. These calculations are performed using a system of computer codes which assess twenty-four peer-reviewed conceptual models. One of those is the cuttings and cavings model, which determines the amount of waste material that would be eroded off a borehole wall due to drilling mud flowing up the borehole during an inadvertent drilling intrusion that intersects the repository. This paper describes the results of several investigations to better constrain the shear strength of the degraded waste material constituting the borehole wall. The lower limit of the range of waste shear strength values is specifically addressed. Based on experimental results on realistic surrogate waste materials, a detailed literature review, and additional analyses it is recommended that the lower value of waste shear strength be changed from 0.05 to 1.50 Pa. In addition to the increase from 0.05 to 1.50 in the lower bound to the range of waste shear strength, a change from log-uniform to a uniform distribution is also recommended for performance assessment calculations. These changes will result in a decrease in the estimated magnitude and frequency of radionuclide releases due to inadvertent human intrusion events. This paper is one of a series of papers describing proposed changes for Waste Isolation Pilot Plant performance assessment calculations as summarized in Nemer et al. [1].

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a deep geologic repository operated by the U.S. Department of Energy (DOE) in southeastern New Mexico as a disposal facility for transuranic (TRU) radioactive waste. The WIPP facility is regulated by the U.S. Environmental Protection Agency (EPA) according to the regulations set forth in Title 40 of the Code of Federal Regulations, Part 191 (40 CFR 191). The DOE demonstrates compliance with the containment requirements according to 40 CFR 194 by means of performance assessment (PA) calculations carried out by Sandia National Laboratories (SNL). WIPP PA calculations estimate the probability and consequences of radionuclide releases from the WIPP repository to the accessible environment for a regulatory period of 10,000 years after closure of the facility. Sandia National Laboratories conducts performance assessments using a system of computer codes. The current WIPP PA technical baseline consists of twenty-four peer-reviewed conceptual models that are developed and implemented in these computer codes.

WIPP PA scenarios include cases of human intrusion in which a future borehole intersects the waste in the repository. Drilling mud flowing up the borehole will apply a shear stress to the borehole wall which, if high enough, could result in erosion of the wall material. This eroded

volume is called "cavings," whereas the volume of the material removed by the drill bit is called "cuttings." Both processes could result in a release of radionuclides being carried up the borehole with the drilling mud and are calculated by the computer code CUTTINGS_S.

WIPP PA uses the parameter BOREHOLE:TAUFAIL (more simply TAUFAIL) to represent the hydrodynamic waste shear strength of the waste in the computer code CUTTINGS_S. For previous WIPP PA analyses the parameter was sampled from a log-uniform distribution with a range of 0.05 to 77 Pa. This range of values was derived by the DOE from literature reviews of erosion tests performed on cohesive sediments and estimation of the mean particle size of WIPP waste [2, 3]. The lower limit of this range of values was chosen to conform to what is hypothesized as an extreme case of degradation of the waste and waste containers.

EROSION OF SOFT COHESIVE SEDIMENTS

Partheniades [4] and Parchure and Mehta [5] discuss the erosion characteristics of soft cohesive sediments, the analog for the most highly degraded state of the waste. They differentiate between two bed types commonly used in erosion testing of sediments, namely placed beds and deposited beds. Placed beds are mechanically placed in the flume or sample holder. Deposited beds are those that result from deposition of sediment settling out of the water column. Both placed and deposited beds can exhibit two modes of failure. The first is "surface erosion." It involves particle by particle or aggregate by aggregate entrainment of surface sediments. This value of shear strength is known as "incipient motion" or the "bed surface strength" and is denoted by τ_{so}. It is defined as the threshold condition between erosion and deposition. The depth at which surface erosion is the expected mode of failure ranges from a couple millimeters in laboratory specimens to a few centimeters in oceanic sediments. The second, known as "bed erosion" or "mass erosion," results from shear loading of the bed. In this case, a plane of failure forms in the bed and erosion takes place by the removal of relatively large pieces of soil. There are two measures of the bed mass strength, the "characteristic strength" (τ_{sc}) and the "operational strength" (τ_c). This paper is predominantly concerned with the operational strength as it represents the more conservative value, yielding the more cautious approach.

Parchure and Mehta [5] and Teeter [6] use graphical methods to determine τ_{so} and τ_c from a plot of the erosion rate ($\dot{\varepsilon}$) versus the bed shear stress (τ_b) or from a plot of suspended sediment concentration at the end of each time step ($C(t)$) versus τ_b. Figure 1 depicts such a plot. The data are typically fit by two linear segments called a piecewise linear fit. The lower (left) segment corresponds to surface erosion. When it is extrapolated to intersect the bed shear stress axis at $\dot{\varepsilon}$ = 0, the abscissa represents τ_{so} [5]. The present value of the lower limit of TAUFAIL = 0.05 Pa is the bed surface shear strength of a San Francisco Bay mud [2]. The upper (right) segment represents the behavior during bed mass erosion. Extrapolation of the upper line to $\dot{\varepsilon}$ = 0 yields the operational shear strength, τ_c [6]. The operational strength represents the lower limit of the bed mass shear strength. The characteristic shear strength, τ_{sc}, is the shear stress at the intersection of the two lines [5].

The different definitions of "critical" shear stress have created some confusion in practice. The determination of τ_{so}, τ_c, and τ_{sc} is based on having sufficient data to create a piecewise linear curve fit, and the fit requires at least two points per line segment. There are numerous instances

where the reported value is based on a single linear fit, as there might be insufficient data, data scatter, or simply the analyst's preference. This single line fit, τ_{sl}, may include all the data or it may be an extension of the upper line of a piecewise linear fit. For purposes of this analysis, we refer to the characteristic strength (τ_{sc}), the operational shear strength (τ_c), and single linear fit at $\dot{\varepsilon} = 0$ (τ_{sl}), as the mass shear strength τ_m (Figure 1). This is considered conservative in that the operational and single line shear strengths will always be less than the characteristic shear strength.
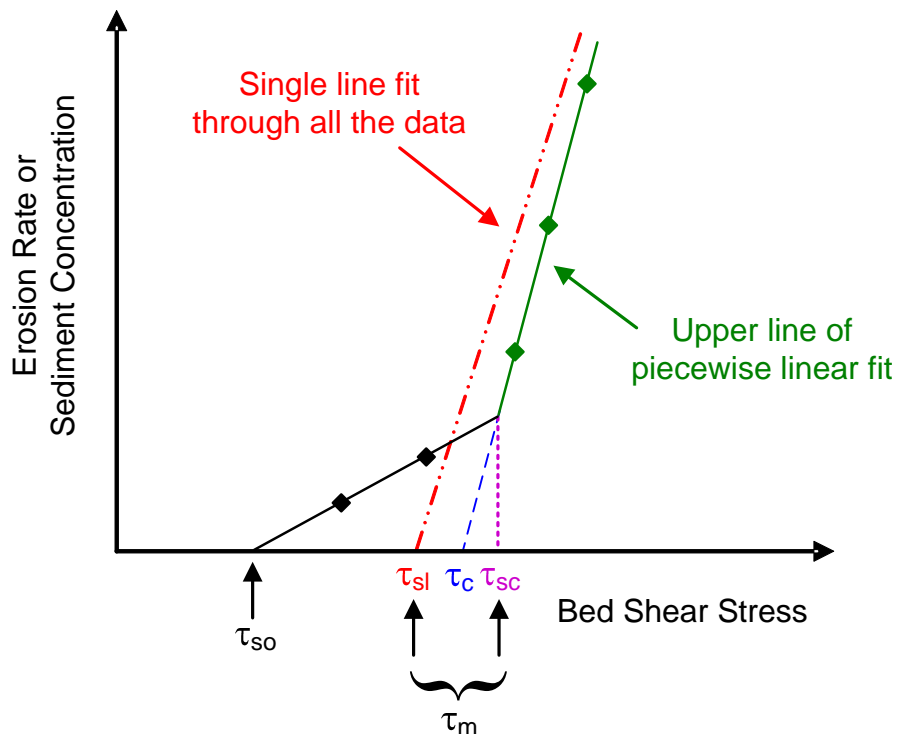

Fig. 1. Determination of surface, τ_{so}, and mass, τ_m, shear stress values as reported in practice. The operation shear strength, τ_c, characteristic strength, τ_{sc}, and single line shear strength, τ_{sl}, are included in the range of mass shear strength values ("τ_m") as often reported in practice.

We recommend using τ_m to represent the shear strength of the waste rather than τ_{so}. The value τ_{so} is a surface phenomenon and would represent flow moving across the top of a sediment bed in a flume experiment or marine environment (Figure 2a). However, in an intrusion event, drilling would cut down through the mass of degraded waste (Figure 2b). The drilling mud would flow up the borehole in a direction perpendicular to the upper surface, if there is one. The strength of the mass of the degraded waste is best represented by the strength of a consolidated or even compacted bed, which is characterized by τ_m [5]. The value τ_m represents the minimum shear strength of the material in the bed. Therefore, use of τ_m as the shear strength of the waste is conservative.

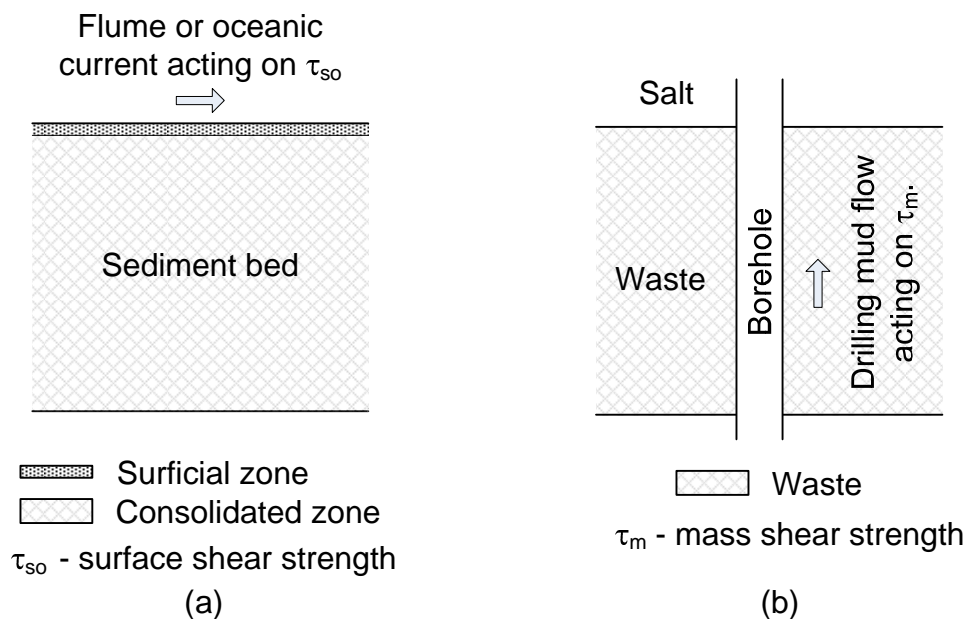**Fig. 2 Schematic of various shear strength values and the direction of the currents acting on them: (a) flume experiment and (b) WIPP repository.**

SURROGATE WASTE MATERIAL DEVELOPMENT

Much of the reason mud or clay was chosen as an analog for the shear strength of the waste was a lack of experimental results on degraded waste. Jepsen et al. [7] performed erosional shear testing on highly degraded surrogate waste samples developed by Hansen et al. [8]. The material was developed in a logical, systematic manner based on consideration of the anticipated future state of the waste considering inventory, evolution of the underground environment, and experimental results.

Conceptualization of the underground, based on waste disposal configurations and analyses of the rock mechanics response, suggested that the most likely future state of the waste materials includes crushing, compaction, and entombment by the surrounding salt. The waste inventory is comprised of massive steel components including standard 55-gallon drums, standard waste boxes, thick steel pipe overpacks, and supercompacted waste "pucks" stored in overpacks. The bulky nature of the compressed inventory makes freeing and transporting of radionuclides extremely difficult. In the most extreme cases, however, the expected processes of iron corrosion and microbial activity can result in predictions of extensive degradation. This end state represents a bounding condition for the waste, which provides a means to quantify the lowest strength conditions of the future state of the waste, and is appropriate for representing the lower bound strength of degraded waste from uncompacted drums and standard waste boxes. Other, denser, waste forms such as pipe overpacks and supercompacted waste packages would be expected to degrade and corrode to a much lesser extent, and therefore will have material characteristics which are much less conservative than those assumed for standard wastes.

Hansen et al. [8] developed their model material from the estimated inventory of standard waste drums. The surrogate waste comprised a mixture of raw materials including iron, glass, cellulosics, rubber, plastic, degradation byproducts, solidification cements, soil, and WIPP salt. They considered degradation of each waste constituent. Subsurface processes leading to extreme degradation are based on several contributing conditions including ample brine availability, extensive microbial activity, corrosion, and the absence of cementation and salt encapsulation effects. The authors asserted that the degraded waste material properties represented the lowest plausible realm of the future waste state because no strengthening processes were included such as compaction, cementation, mineral precipitation, more durable packaging and compressed waste, and less corrosion. It is believed that the samples used by Jepsen et al. [7] represent an unobtainable degraded state of the waste and are thus far weaker than any possible future state, and will cover any changes that may occur in the waste inventory [8, 9].

FLUME EXPERIMENTS ON SURROGATE WASTE MATERIALS

Jepsen et al. [7] performed their tests using a flume apparatus (Sedflume) which incorporates a 10 cm wide by 15 cm long sample section. The material erodes during a test as an operator continuously moves the sample upwards such that the sample-water interface remains level with the bottom of the flume. Erosion rate is recorded as the upward movement as a function of time. Several types of waste materials were tested including 50 % degraded surrogate material (five samples designated as B2 through B6) and 100 % degraded surrogate material (three samples designated as B7 through B9). Percent of degradation refers to the amount of initial iron-based and cellulosics, plastics, and rubber (CPR) inventory that is corroded.

Table I gives the values of τ_{so} and τ_m as calculated based on piecewise linear curve fitting, if possible, using Jepsen et al. [7] test data on surrogate waste material. An example of the piecewise linear curve fitting methodology is shown in Figure 3a for Sample B2. This methodology yields shear strength values of τ_{so} and τ_c. If a piecewise fit is not possible, the mass shear strength is based on a strictly linear fit of the data (τ_{sl}). An example of the single linear curve fitting methodology is shown in Figure 3b for Sample B3. Complete data analyses are given in Herrick et al. [10]. Jepsen et al.'s reported critical shear stress values are given in the last column. The Jepsen et al. values were obtained as an interpolated shear stress at an erosion rate of 10^{-4} cm/s.

The 50% degraded surrogate waste material was accepted for use in obtaining the parameters for the other WIPP PA models [11]. Hansen et al. [9] showed that for the vast majority of their performance assessment calculations, half or more of the initial iron and CPR inventory remains. Since their approach was deemed to be adequate by a previous conceptual model peer review panel [11] and the EPA for the development of parameters for the spallings model, we recommend following their approach to establish consistency between models. Therefore, it is recommended that the experimental results for the 50% degraded samples be accepted to establish the lower limit of TAUFAIL. Using this approach, the average shear strength of the recommended surrogate materials is 1.50 Pa (see Table I).

Table I. Summary of Shear Strengths for Surrogate Waste Materials from Present Analysis and Jepsen et al. [7].

Sample	Piecewise Linear Fit		Jepsen et al. Critical Shear Strength Values [Pa]
	Bed Surface Shear Strength (τ_{so}) [Pa]	Mass Shear Strength (τ_m) [Pa]	
50% degraded			
B2 [a]	0.47	1.94	1.67
B3 [b]	—	2.11	2.20
B4 [b]	—	1.25	1.06
B5 [c d]	—	0.80	0.72
B6 [d]	—	1.40	1.40
average	0.47	1.50	1.41
100% degraded			
B7 [a]	0.18	0.35	0.22
B8 [a]	0.27	0.59	0.30
B9 [a]	0.26	0.51	0.34
average	0.24	0.48	0.29

Notes: [a]   Sufficient data for piecewise linear curve fit. Shear strength is characterized by bed surface shear strength (τ_{so}) and the operational shear strength (τ_c).
[b]   Insufficient data for piecewise linear curve fit. A single line was used to fit the data. Shear strength is characterized by τ_{sl}.
[c]   Test series incomplete and was stopped at one shear stress level because flow meter was destroyed by debris at the next level.
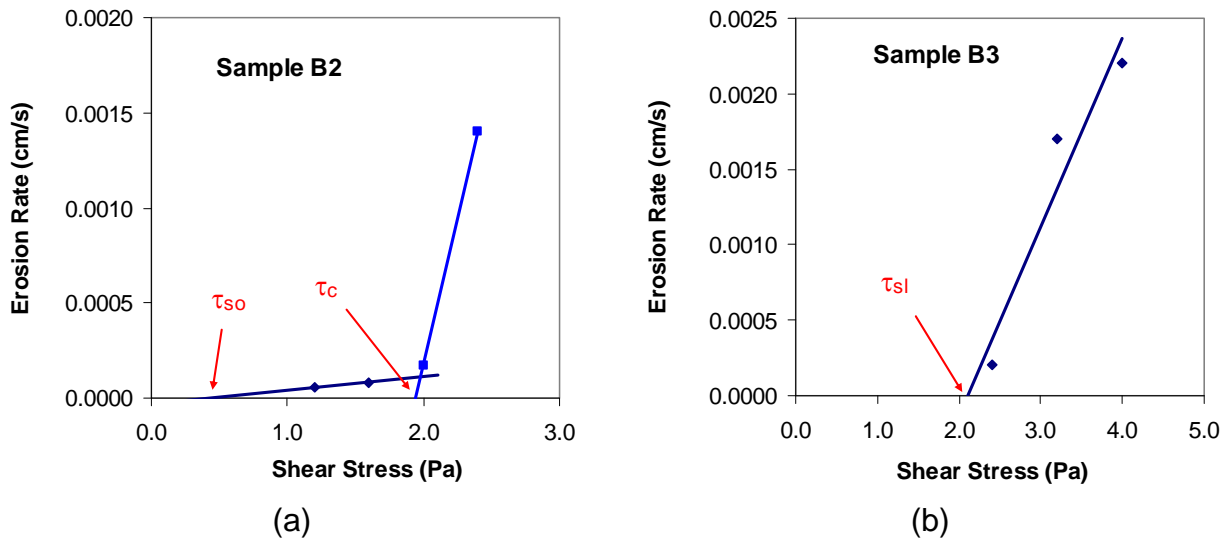[d]   Insufficient data for piecewise linear or linear curve fit. Average shear stress value used.

(a)

(b)

Fig. 3. Plots of the erosion rate versus bed shear stress. (a) Example of piecewise linear fit for Sample B2 characterized by τ_{so} and τ_c. (b) Example of single line fit for Sample B3 characterized by τ_{sl}.

REVIEW OF ANALYSIS BASED ON EXPERT PANEL'S PARTICLE DISTRIBUTION

Between the Compliance Certification Application (CCA) and the Performance Assessment Verification Test (PAVT), the EPA suggested that the waste shear strength be estimated based on particle size distributions and the Shields curve [12]. The Shields curve is a measure of threshold condition between erosion and sedimentation of a single particle, a condition referred to as incipient motion. However, the waste particle diameter was identified by the EPA as lacking supporting evidence [13] and requiring derivation through expert judgment [12]. The DOE's approach to estimate TAUFAIL using the Shields curve was to follow the method described in Simon and Senturk [14]. Based on an analysis of the Expert Panel Elicitation results [3], the lower limit of the mean particle size of WIPP waste was estimated to be 1 mm, while the upper limit was determined to be either 10 cm assuming no cementation or approaching room size when cementation occurs [15]. Mean particle sizes averaged on volume fractions are used to calculate TAUFAIL [16].

The results of Wang and Larson's [16] analysis are reproduced below in Table II. The range of mean particle diameters of interest yields values for the critical shear stress of WIPP waste as 0.64 Pa for 1 mm particles and 76.52 Pa for 10 cm particles. The EPA [17, 18] directed that the CCA lower limit value for TAUFAIL of 0.05 Pa be retained for conservativism and the DOE accepted its use.

The particle size distribution as determined by the Expert Panel Elicitation fills one of the gaps mentioned by the Conceptual Model Peer Review [19] in that it provides knowledge of the future state of the waste.

Table II. Waste Shear Strengths Calculated as a Function of Waste Mean Particle Diameter Using the Shields Curve (Wang and Larson [16], Table 2). Highlighted Particle Sizes Represent the Minimum and Maximum Sizes Expected in WIPP [3, 15].

Particle diameter d_g (m)	Grain Scale Reynold's Number	Shields Parameter ψ_c	TAUFAIL (τ_{so}) (Pa)
1.00E-04	17	0.033	0.04
1.00E-03	170	0.05	0.64
5.00E-03	850	0.06	3.83
1.00E-02	1700	0.06	7.65
2.00E-02	3400	0.06	15.30
5.00E-02	8500	0.06	38.26
6.00E-02	10200	0.06	45.91
8.00E-02	13600	0.06	61.21
1.00E-01	17000	0.06	76.52
2.00E-01	34000	0.06	153.04

WASTE SHEAR STRENGTH BASED ON LITERATURE REVIEW AND EXPERT PANEL ELICITATION RESULTS

As discussed previously, there are basically three different definitions of "critical" shear stress, namely incipient motion or surface erosion (τ_{so}), operational shear stress (τ_c), and characteristic shear strength (τ_{sc}) for erosion experiments that can be characterized by a piecewise linear fit (see Figure 1). In some cases the data can only be fit by a single linear curve fit, yielding τ_{sl} at $\dot{\varepsilon} = 0$. For purposes of this paper, we refer to τ_{sc}, τ_c, and τ_{sl} as the mass shear strength τ_m. With this terminology in mind, an extensive literature review was conducted to obtain published critical shear strength data (Herrick et al. [20]). Figure 4 shows a plot of the surface and mass shear strength values as a function of moisture content based on literature data.
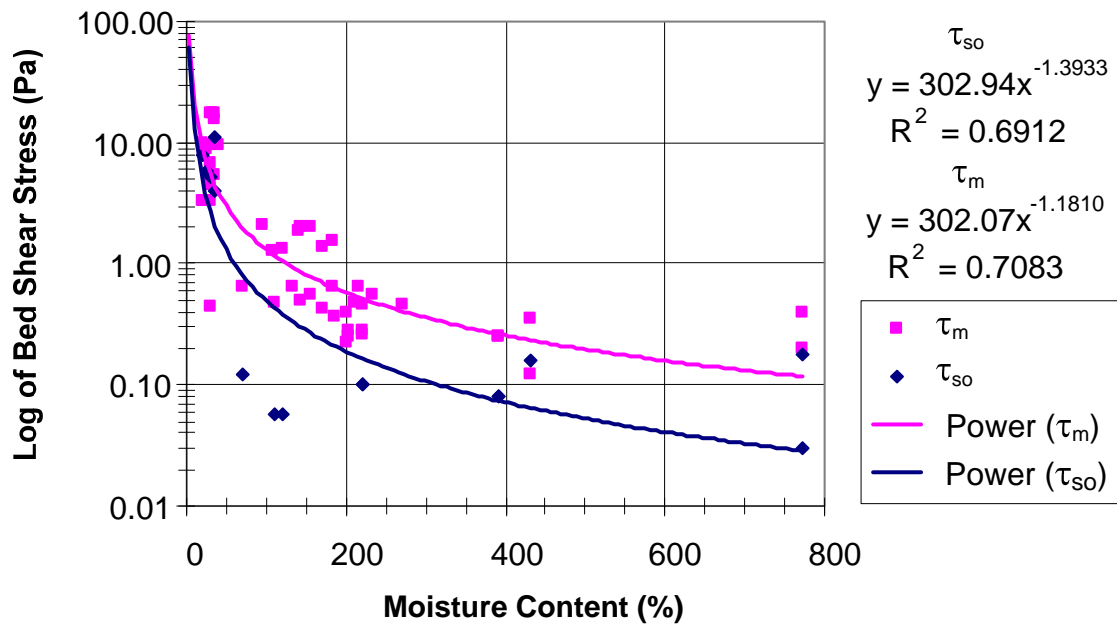

Fig. 4. Plot of all surface (τ_{so}) and mass shear strength (τ_m) values from the literature review by Herrick et al. [20].

One observes from this figure that the critical shear stress values decrease significantly with increasing moisture content. Using standard regression methods, a power law curve fit appears to best match the data. The "best fit" curves shown in Figure 4 give the following relationships:

Bed surface shear strength:

$$\tau_{so} = 302.94(w)^{-1.3933} \tag{Eq. 1}$$

Mass shear strength:

$$\tau_m = 302.07(w)^{-1.1810} \tag{Eq. 2}$$

where the shear stresses τ_{so} and τ_m are given in Pascals and the moisture content w is defined as the ratio of the mass of the water to the mass of the solids and is given in percent.

Figure 4 provides a correlation between τ_{so} and τ_m which we can use to estimate a value of τ_m from τ_{so}. From Wang and Larson [16], the lower value of τ_{so} is 0.64 Pa (see Table II). Using $\tau_{so} = 0.64$ Pa in Equation 1, taking the logarithm of both sides, and rearranging terms, one obtains a moisture content of 83%. Using this moisture content in Equation 2, the corresponding value of τ_m is 1.63 Pa. This is quite close to the experimentally obtained values of 1.50 Pa [10] (see Table I). Therefore, the results from the Expert Panel Elicitation on particle size, when combined with a detailed literature survey, provide independent confirmation of the experimental results performed on surrogate waste materials.

PROPOSED MODIFICATION FOR TAUFAIL

The parameter BOREHOLE:TAUFAIL represents the shear strength of degraded waste material in WIPP PA as it is applied in the cavings model of the code CUTTINGS_S. The lower limit of the range of values used for TAUFAIL is presently set at 0.05 Pa, a value that was based on the shear stress required to cause incipient motion in a San Francisco Bay mud [2].

We have noted in this paper that we do not believe that the values obtained for incipient motion are the values that should be used for the waste. The value of shear strength for incipient motion, denoted by τ_{so}, is a surface phenomenon that pertains only to the first few millimeters or centimeters of a sediment bed. In the repository, a drillbit penetrating the waste will drill in a direction through the interior of the waste (Figure 2b). In this case, the erosion will be occurring on a more dense material within the waste mass which is more able to resist erosion. In erosion experiments, Partheniades [4] and Parchure and Mehta [5] noted that there is a specific shear stress beyond which erosion of the bed at depth takes place. We determined this mass shear strength of the bed (τ_m) as the most conservative representation of the behavior of the bed mass. Typical erosion test results can be well represented by two lines (a piecewise linear fit) where the extrapolation of the upper line to $\dot{\varepsilon} = 0$ represents τ_c (Figure 1). If there is no piecewise linear fit, e.g., insufficient data, data scatter, or author's preference, then the data is interpreted by a single line fit through all the data (τ_{sl}). The mass shear strength of the bed is given by the shear strength measure that describes the data best, either τ_c or τ_{sl}. In either case, τ_m is the minimum value for the bed mass as a whole.

The CCA Conceptual Model Peer Review Panel [19] pointed out that proper assessment of this parameter value would require experimental data obtained on materials representative of that which would be present in the repository at the time of intrusion. After the CCA was completed, experimental results were obtained on surrogate waste materials that are believed to represent an unobtainable degraded state of the waste. The strength of the materials are anticipated to be far weaker than the waste found under any possible future state, including any percentage changes that may occur in the waste inventory [8, 9]. Analysis of those results using the method of Parchure and Mehta [5] for the 50% degraded material yields a lower limit for TAUFAIL of 1.50 Pa. This value is consistent with critical shear strength value of 1.41 Pa calculated by Jepsen et al. [7] using their methodology.

In addition, the Conceptual Model Peer Review Panel also noted that there was an absence of accurate waste characterization or knowledge of the form of the waste at the time of intrusion. An Expert Panel Elicitation [3] was convened to address that deficiency. Using the results of their judgment on the future state of the waste in conjunction with the results of a comprehensive literature review [16, 20] yields a bed mass shear strength for the lower limit of 1.63 Pa. This result adds independent credibility to those obtained experimentally.

In view of the above discussion, it is recommended that BOREHOLE:TAUFAIL be assigned a lower limit of 1.50 Pa. In addition, it is recommended that the probability distribution for TAUFAIL be changed from log-uniform to uniform since the new distribution now spans less than two orders of magnitude, i.e., 1.5×10^{0} to 7.7×10^{1}. In WIPP PA methodology, the use of a uniform distribution is appropriate when all that is known about a parameter is its range, as is the case here for TAUFAIL. The uniform distribution is the maximum entropy distribution under these circumstances. Log-uniform distributions are appropriate for parameters that span many orders of magnitudes [21]. Table III compares TAUFAIL properties used in the 2004 Compliance Recertification Application WIPP PA technical baseline (CRA-2004 PABC) with those proposed for use.

Table III. Comparison of BOREHOLE:TAUFAIL Parameter Characteristics.

Analysis	Range	Distribution
CRA-2004 PABC	0.05 – 77.0 Pa	Log-uniform
Proposed	1.50 – 77.0 Pa	Uniform

HOW CHANGES TO TAUFAIL WOULD AFFECT RELEASES

The CUTTINGS_S code calculates the quantity of waste materials brought to the surface by cuttings and cavings as a consequence of an inadvertent drilling intrusion into the WIPP repository. The volume of waste materials removed by cuttings and cavings is assumed to be a cylinder, and the CUTTINGS_S code reports the area of the base of that cylinder. Thus, all results discussed in this section are stated in terms of cuttings and cavings areas (in units of m^2). To calculate the uncompacted volume of cuttings and cavings, the area should be multiplied by the uncompacted height of the repository, 3.96 m.

The cuttings and cavings areas were calculated for the CRA-2004 PABC replicates (a replicate is 100 sets of vectors, and a vector is one set of parameter combinations) and using the proposed change to TAUFAIL. Cuttings results are the same for each set of parameter combination since they are determined by the diameter of the drillbit, which has a constant value of 0.31 m (12.25 in). Two sampled parameters affect cavings results, the waste shear strength (BOREHOLE:TAUFAIL) and the angular velocity of the drill string (BOREHOLE:DOMEGA). The combination of these two parameters determines the amount of cavings.

We are proposing modification of the shear strength parameter BOREHOLE:TAUFAIL to include two changes, namely, increase the lower bound range of sampled shear strengths from 0.05 to 1.5 Pa and change the probability distribution from log-uniform to uniform due to the

range of parameters being less than two orders of magnitude. Both of these changes will generally result in higher sampled shear strength values. In the cavings model, the borehole diameter is assumed to grow until the shear stress on the borehole wall is equal to the shear strength of the waste, and, thus, higher shear strengths result in smaller cavings volumes. Consequently, when the proposed changes to TAUFAIL are implemented, cavings areas decrease relative to the corresponding CRA-2004 PABC values.

Table IV contains the summary statistics for cuttings and cavings areas using the proposed TAUFAIL changes. Changing the shear strength distribution decreased the frequency and magnitude of cavings. Forty-nine of the 100 proposed replicate R1 vectors had no cavings. In contrast, nine of the 100 CRA-2004 PABC replicate R1 vectors had no cavings. The minimum area calculated in both analyses was 0.760 m^2. The vectors with this area do not experience shear stresses large enough to cause cavings, and so the minimum area is simply the area of drillbit that causes cuttings. The mean cuttings and cavings area using the proposed changes in TAUFAIL was 0.0869 m^2, and the maximum cuttings and cavings area for this replicate was 0.190 m^2. The proposed replicate R1 maximum area is less than the mean area of CRA-2004 PABC replicate R1 (0.253 m^2), and the maximum CRA-2004 PABC area for replicate R1 was 0.824 m^2, more than four times larger than the maximum using the proposed changes.
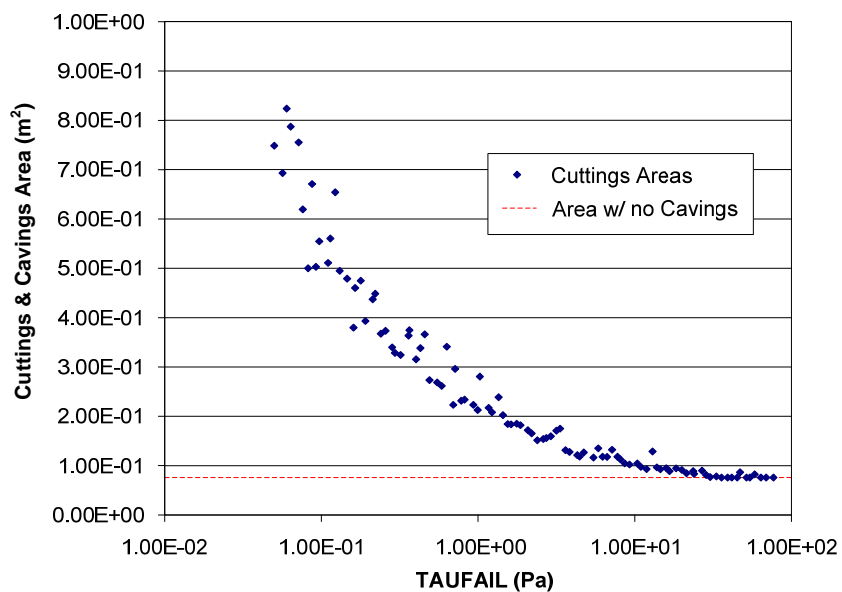
Table IV. Comparison of Cuttings and Cavings Area Statistics for Replicate R1. CRA-2004 PABC Results are from Table 7 in Vugrin [22].

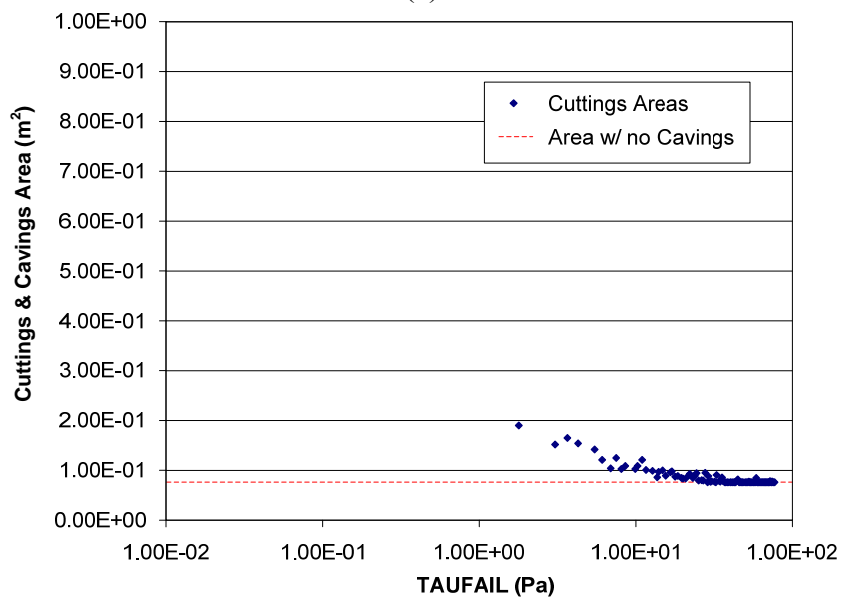| Analysis	Minimum (m^2)	Maximum (m^2)	Mean (m^2)	Vectors without Cavings
CRA-2004 PABC	0.076	0.824	0.253	9
Proposed	0.076	0.190	0.0869	49

To analyze the sensitivity of cavings to the waste material shear strength, scatter plots were developed. Figure 5 indicates that lower shear strengths lead to larger cavings amounts in both the CRA-2004 PABC and calculations with the proposed modifications. This observation agrees with the cavings model because the shear strength of the material is the limiting shear stress below which the erosion of the waste ceases. It is also evident that increasing the lower bound of the waste shear strength parameter decreased the frequency and magnitude of cavings volumes and releases from CRA-2004 PABC estimates.

SUMMARY

WIPP PA consists of twenty-four conceptual models that describe various features of the repository system. According to regulatory requirements for the WIPP, these conceptual models were submitted for peer review prior to the initial certification of the WIPP. Following the certification, continued experiments and analyses have been performed to gain further understanding of the repository system. DOE has identified aspects of WIPP PA that could be refined by incorporating the results of some repository investigations into PA models. Inclusion of the results of these analyses in WIPP PA models will result in a more accurate representation of the repository and better but still conservative predictions of the long term performance.

(a)

(b)

Fig. 5. Scatter plots of cuttings and cavings areas versus TAUFAIL for replicate R1: (a) of CRA-2004 PABC (Vugrin [22], Figure 1) and (b) using the proposed changes to TAUFAIL. The dashed red line represents the cuttings area, i.e., the maximum area without cavings.

The DOE has proposed to modify the waste shear strength parameter TAUFAIL in the Cuttings and Cavings conceptual model. In the current PA technical baseline, the waste shear strength is sampled from a log-uniform distribution that ranges from 0.05 Pa to 77 Pa. Since lower shear strengths result in greater cavings, the conservatively small lower bound was selected since the DOE lacked experimental data during the initial peer review of the Cuttings and Cavings

conceptual model. After the shear strength parameter was first established, a set of erosional shear testing experiments have been conducted on highly degraded surrogate waste, and the results of these experiments suggest that the lower bound of the waste shear strength parameter should be increased from 0.05 to 1.50 Pa. Thus, it is proposed that the waste shear strength be modeled as a uniform distribution with a range of 1.50 to 77.0 Pa. Simulations undertaken with the proposed changes to TAUFAIL show that the frequency and magnitude of cavings volumes and releases from CRA-2004 PABC estimates decrease as a result of implementing the changes.

ACKNOWLEDGEMENTS

REFERENCES

1. M.B. NEMER, S.C. DUNAGAN, and E.D. VUGRIN, "Prioritization of Technical Content and Impact Assessment for Changes to Performance Assessment at the Waste Isolation Pilot Plant (WIPP) – 8086," Proceedings WM2008 Conference, February 24-28 2008, Phoenix, AZ (2008).
2. J.W. BERGLUND, "Effective shear resistance to erosion TAUFAIL," memorandum to B.M. Butcher, October 28, 1996, ERMS 247189, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1996).
3. CTAC (Carlsbad Area Office Technical Assistance Contractor), "Expert Elicitation on WIPP Waste Particle Diameter Size Distribution(s) During the 10,000-year Regulatory Post-closure Period: Final Report," ERMS 541365, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1997).
4. E. PARTHENIADES, Erosion and deposition of cohesive soils, Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, vol. 91, no. HY1, pp. 105-139 (1965).
5. T.M. PARCHURE and A.J. MEHTA, Erosion of soft sediment deposits, Journal of Hydraulic Engineering, vol. 111, no. 10, pp. 1308-1326, (1985).
6. A.M. TEETER, "Alcatraz Disposal Site Investigation, Report 3: San Francisco Bay-Alcatraz Disposal Site Erodibility," Miscellaneous Paper HL-86-1, AD Number A181837 Department of the Army, Waterways Experimental Station, Corps of Engineers, Vicksburg, MS (1987).
7. R. JEPSEN, J. ROBERTS, and W. LICK, "Development and Testing of Waste Surrogate Materials for Critical Shear Stress," ERMS 533809, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1998).
8. F.D. HANSEN, M.K. KNOWLES, T.W. THOMPSON, M. GROSS, J.D. MCLENNAN, and J.F. SCHATZ, "Description and Evaluation of a Mechanistically Based Conceptual Model for Spall," SAND97-1369, Sandia National Laboratories, Albuquerque, NM (1997).
9. F.D. HANSEN, T.W. PFEIFLE, and D.L. LORD, "Parameter Justification Report for DRSPALL," SAND2003-2930, Sandia National Laboratories, Albuquerque, NM (2003).

10. C.G. HERRICK, M. RIGGINS, B.Y. PARK, and E.D. VUGRIN, "Recommendation for the Lower Limit of the Waste Shear Strength (Parameter BOREHOLE : TAUFAIL), Rev. 1," ERMS 546343, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (2007a).
11. C. YEW, J. HANSON, and L. TEUFEL, "Waste Isolation Pilot Plant Spallings Conceptual Model Peer Review Report," ERMS 532520, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (2003).
12. E.R. TROVATO, Letter to G. Dials (DOE), April 25, 1997, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, Docket A-93-02, II-I-27 (1997b).
13. E.R. TROVATO, Letter to G. Dials (DOE), April 17, 1997, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, Docket A-93-02, II-I-25 (1997a).
14. D.B. SIMON and F. SENTURK, Sediment Transport Technology: Water and Sediment Dynamics, Sedimentation Engineering Manual No. 54, American Society of Civil Engineers, Water Resources Publication (1992).
15. Y. WANG, "Estimate WIPP waste particle sizes based on expert elicitation results: revision 1," memorandum to M.S.Y. Chu and M.G. Marietta, Aug 5, 1997, ERMS 246936, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1997).
16. Y. WANG and K.W. LARSON, "Estimate waste critical shear stress for WIPP PA caving model," memorandum to M.S.Y. Chu and M.G. Marietta, June 27, 1997, ERMS 246696, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1997).
17. M. KRUGER, "Performance assessment parameter values identified in EPA letters, dated April 17 and 25, 1997, to DOE," Docket A-93-02, II-I-33. (1997).
18. U.S. ENVIRONMENTAL PROTECTION AGENCY, "Technical Support Document for Section 194.23: Parameter Justification Report," Docket A-93-02, V-B-14 (1998).
19. U.S. DEPARTMENT OF ENERGY, Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant, DOE/CAO-1996-2184, Appendix Peer, Peer 1, "Conceptual Models Peer Review Report (July 1996)," Section 3.13 (1996).
20. C.G. HERRICK, M. RIGGINS, and B.Y. PARK, Recommendation for the Lower Limit of the Waste Shear Strength (Parameter BOREHOLE : TAUFAIL), Rev. 0, ERMS 546033 WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (2007b).
21. M.S. TIERNEY, "Distributions," ERMS 235268, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (1996).
22. E.D. VUGRIN, "Analysis Package for CUTTINGS_S, CRA 2004 Performance Assessment Baseline Calculation," ERMS 540468, WIPP Records Center, Sandia National Laboratories, Carlsbad, NM (2005)