543541

date: June 19, 1984

Sandia National Laboratories
SAND2016-3647R
Albuquerque, New Mexico 87185

to: D. E. Munson, 6332

from: H. S. Morgan and R. D. Krieg, 1521

subject: Updated Drucker-Prager Constants for Anhydrite and Polyhalite

The Waste Isolation Pilot Plant (WIPP) reference stratigraphy [1] contains layers of both anhydrite and polyhalite which must be included in models used to compute the response of WIPP rooms and drifts. These layers have usually been modeled as elastic materials [2,3,4] due to the ease in implementing elastic models. However, laboratory test data [5,6] suggest that Drucker-Prager or Mohr-Coulomb plasticity models are more appropriate. In addition, stresses computed with the elasticity models were unrealistically high for anhydrite layers near rooms and drifts [2,3,4]. Furthermore, a parameter study based on the South Drift configuration [4] indicated that closures obtained with a crude elastic-plastic model for anhydrite were much larger than closures obtained with elastic anhydrite models. The use of Drucker-Prager models for anhydrite and polyhalite was also recommended at a workshop to evaluate WIPP drift models [7].

WIPP reference models for both anhydrite and polyhalite are currently defined as Drucker-Prager models [1]. However, the reference models predict failures under purely hydrostatic tensile loading which are unrealistically high as will be explained below. Thus, we reexamined the current reference Drucker-Prager models and suggest that the updates described in this memo be used in the pretest reference calculations for the WIPP in situ experiments.

In the Drucker-Prager models for anhydrite and polyhalite, the materials are linear elastic until failure occurs. The failure criterion is expressed as

$$\sqrt{J_2'} = C - a J_1 \qquad (1)$$

where $\sqrt{J_2'}$ is the second invariant of the deviatoric stresses, J_1 is the first invariant of the total stresses with tensile stresses taken to be positive, and C and a are the Drucker-Prager constants. Alternatively, the failure criterion can be expressed in terms of the mean stress σ_m as

$$\sqrt{J_2'} = C - b \sigma_m \qquad (2)$$

where σ_m is $J_1/3$ and b is 3a. In either case, the resulting failure surface is conical about the hydrostatic axis.

WIPP: 1.2.7: PDD: NQ: PKG 509446

WIPP reference values of C and a are given in [1] for both yield and ultimate failure. For anhydrite undergoing yield failure, C is 33 MPa and a is 0.226 (b is 0.678). These values were obtained from a least squares fit of the laboratory test data [5] shown in Figure 1. In the tests, the compressive mean stress was always greater than 25 MPa. However, in situ compressive mean stresses at the WIPP site are less than 16 MPa. Extrapolation of the test data using the fit corresponding to the constants given above indicates that anhydrite yields under pure deviatoric loading ($\sigma_m = 0$) at 33 MPa. In addition, failure under pure hydrostatic tension, that is, the position of the apex of the conical yield surface, occurs at a tensile mean stress of 48.7 MPa. Examination of anhydrite cores from the WIPP site and the presence of cracked anhydrite layers in the floors of WIPP test rooms [7] indicate that these values for failure are probably unrealistically high. The values of C and a obtained by fitting the ultimate stress data for anhydrite and by fitting both the yield and ultimate stress data for polyhalite also imply failure under hydrostatic tension at unrealistically high values of σ_m.

Motivated by these observations, we tried to improve the Drucker-Prager models in the low mean stress region. First, we combined anhydrite failure data from RE/SPEC [6] with the Sandia data [5] to increase the data base. We also combined yield and ultimate stress data from both sources [5,6] to increase the data base even further. For polyhalite, only the Sandia data [5] was available so we could only combine the yield and ultimate stress data from this one source. Combining the yield and ultimate failure data seemed appropriate because the anhydrite observed in situ probably undergoes both types of failure and an average model would be the easiest way to account for both types of failure. The enlarged data base for anhydrite is shown in Figure 2 along with two fits of the data. One fit represents the reference Drucker-Prager model for yield failure (C = 33 MPa, a = 0.226, b = 0.678), and the other represents a new model which will be explained in the following paragraphs. Addition of the RE/SPEC data provides failure data for compressive mean stresses as low as 10 MPa. These data show that the reference fit could be improved. However, even with the RE/SPEC data, the failure behavior of anhydrite for mean stresses near zero still must be resolved. Thus, the second step in obtaining the new fit shown in Figure 2 was to reconsider the behavior in this region.

Two assumptions about anhydrite behavior in the zero mean stress region were made. One was that the Drucker-Prager model was still valid at low mean stresses. That is, we assumed that the failure surface was conical. This assumption could be challenged because a parabolic or other nonlinear function might fit the data in Figure 2 as well as or better than the straight lines associated with Drucker-Prager models. Conversely, the data are not good enough to justify a fit more complex than the conical fit. The other assumption was that failure under pure hydrostatic tension occurred at a tensile mean stress of 1.0 MPa. This assumption was based on qualitative observations of anhydrite specimens. The material breaks easily in one's fingers when force is applied, yet it remains intact in the absence of pressure. Thus, the apex of the conical failure surface must be located in the tensile region, but the magnitude of the mean stress must be low. A tensile mean stress of 1.0 MPa is a reasonable value.

Using these assumptions, we determined new Drucker-Prager constants for the anhydrite data in Figure 2 by using a least squares fit of the data with the additional constraint that the deviatoric failure stress had to be zero at a tensile mean stress of 1 MPa. The new values of C, a, and b for anhydrite are 1.35 MPa, 0.45, and 1.35, respectively. The same reasoning, including the use of 1.0 MPa mean stress intercept, was applied to determine new Drucker-Prager constants for the polyhalite data in Figure 3. The new values of C, a, and b for polyhalite are 1.42 MPa, 0.473, and 1.42, respectively. These new data fits are shown for anhydrite in Figure 2 and for polyhalite in Figure 3.

The new Drucker-Prager models were used in a South Drift calculation, and the results were compared to South Drift results obtained with elastic models for anhydrite and polyhalite. Closures obtained in the calculations were almost identical (within 2%). Stresses in the anhydrite layers and polyhalite layer away from the drift were also the same regardless of the whether the elastic or the Drucker-Prager models were used. This was to be expected because the deviatoric stresses away from the drift are small and the layers do not yield. For the two anhydrite layers closest to the drift, which are shown in Figure 4, the stresses obtained with the Drucker-Prager models are approximately 10% less than the stresses obtained with elastic models. This indicates that a small amount of plasticity has occurred in these layers. Thus, for the South Drift, the use of the Drucker-Prager models for anhydrite and polyhalite does not change the results substantially. However, for configurations in which anhydrite layers are located in the pillars of drifts, such for the heated WIPP in situ experiments, more plasticity will occur in the anhydrite layers, and the use of the appropriate Drucker-Prager models will become an important if not dominant factor.

REFERENCES

1. Krieg, R. D., "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant (WIPP) Project," SAND83-1908, Sandia National Laboratories, Albuquerque, NM, January 1984.

2. Morgan, H. S., Krieg, R. D., and Matalucci, R. V., "Comparative Analysis of Nine Structural Codes Used in the Second WIPP Benchmark Problem," SAND81-1389, Sandia National Laboratories, Albuquerque, NM, November 1981.

3. Miller, J. D., Stone, C. M., and Branstetter, L. J., "Reference Calculations for Underground Rooms of the WIPP," SAND82-1176, Sandia National Laboratories, Albuquerque, NM, August 1982.

4. Morgan, H. S., Webb, D. M., Stone, C. M., and Krieg, R. D., "South Drift Analyses," (Memo to D. E. Munson, 6332 dated January 20, 1984), Sandia National Laboratories, Albuquerque, NM.

5. Teufel, L. W., "Mechanical Properties of Anhydrite and Polyhalite in Quasi-Static Triaxial Compression," SAND81-0858, Sandia National Laboratories, Albuquerque, NM, October 1981.

6. Senseny, P. E., Fossum, A. F., and Pfeifle, T. W., "Non-Associative Constitutive Laws for Low Porosity Rocks," International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 7, 1983, p. 101-115.

7. Krieg, R. D., et al, "Conclusions of February 6-7, 1984 WIPP Workshop," (Memo to L. D. Tyler, 6332 dated February 16, 1984), Sandia National Laboratories, Albuquerque, NM.

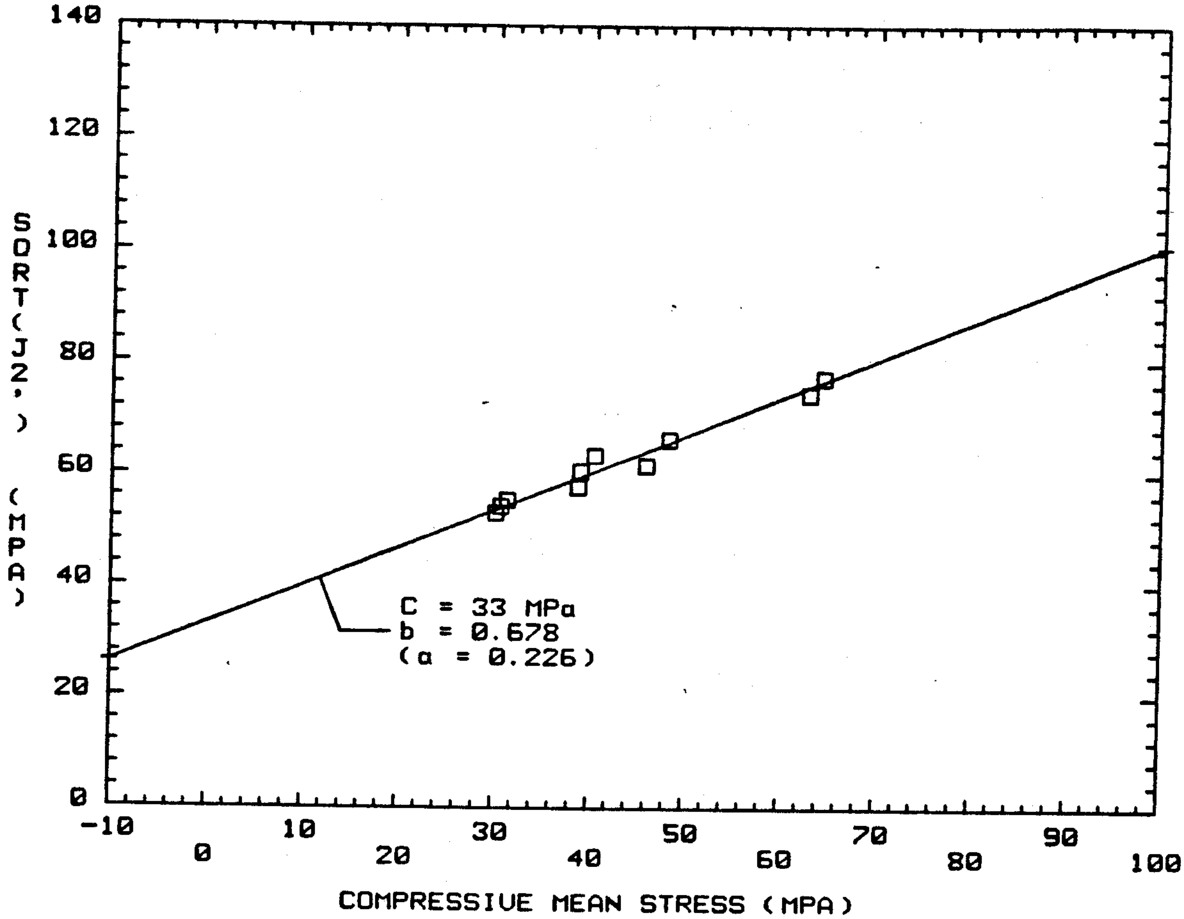

Figure 1. Yield Failure Data for Anhydrite [5].

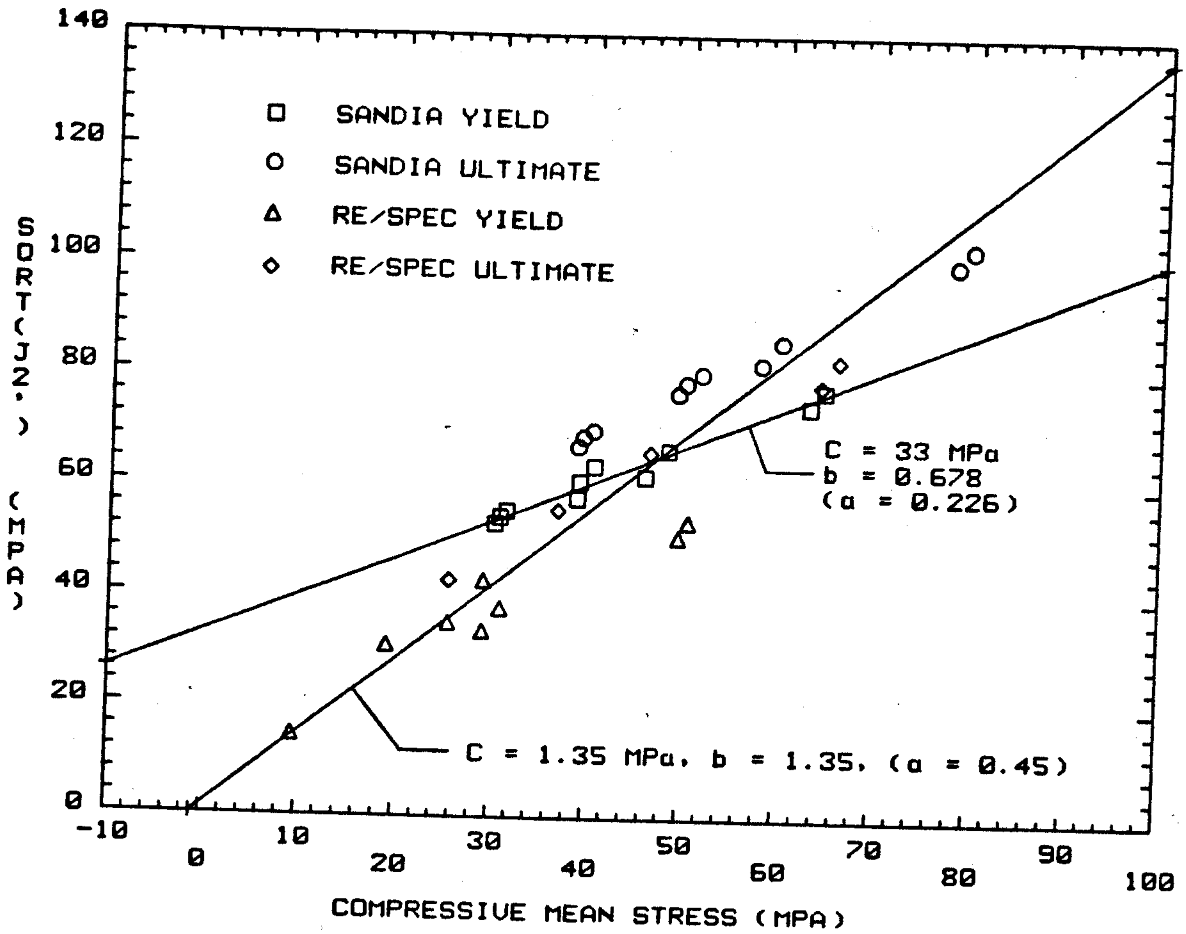

Figure 2. Failure Data for Anhydrite [5,6].

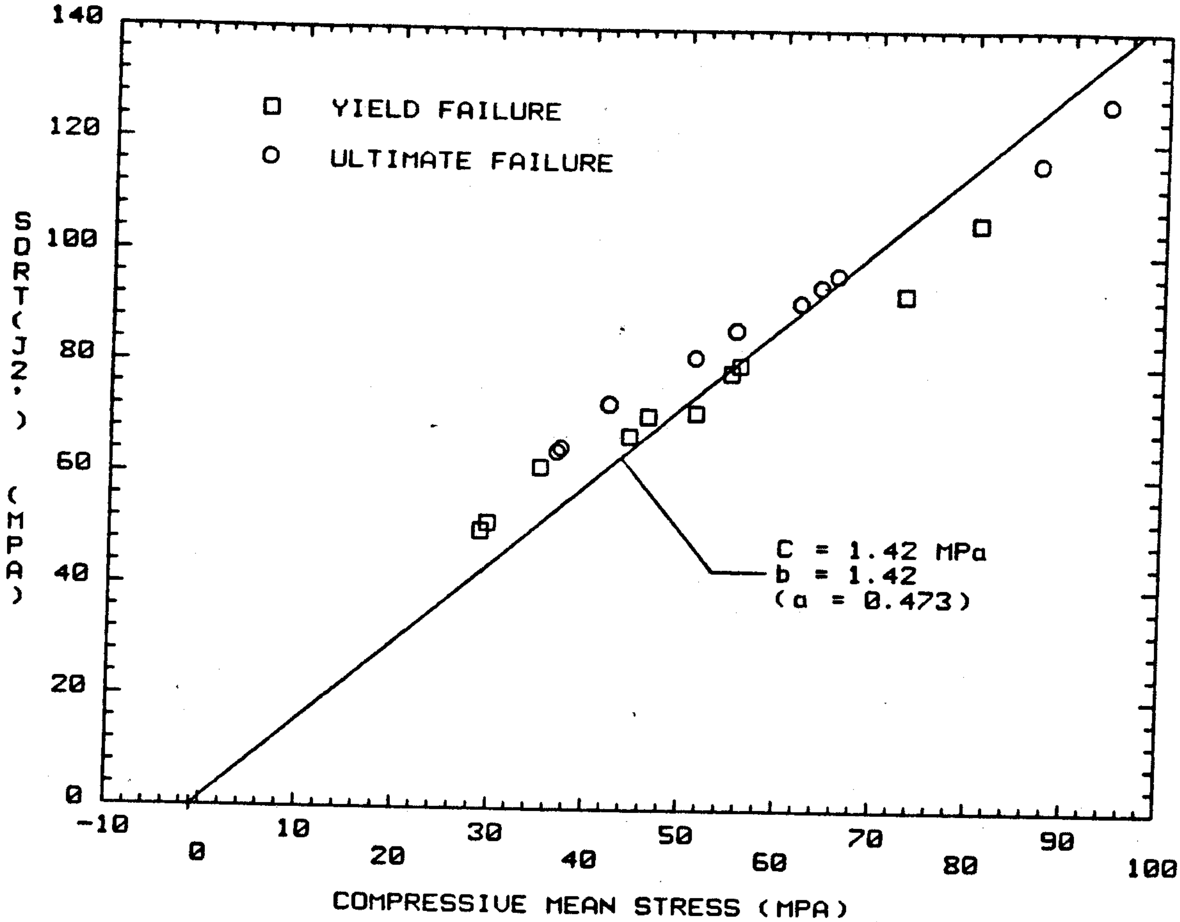

Figure 3. Failure Data for Polyhalite [5].

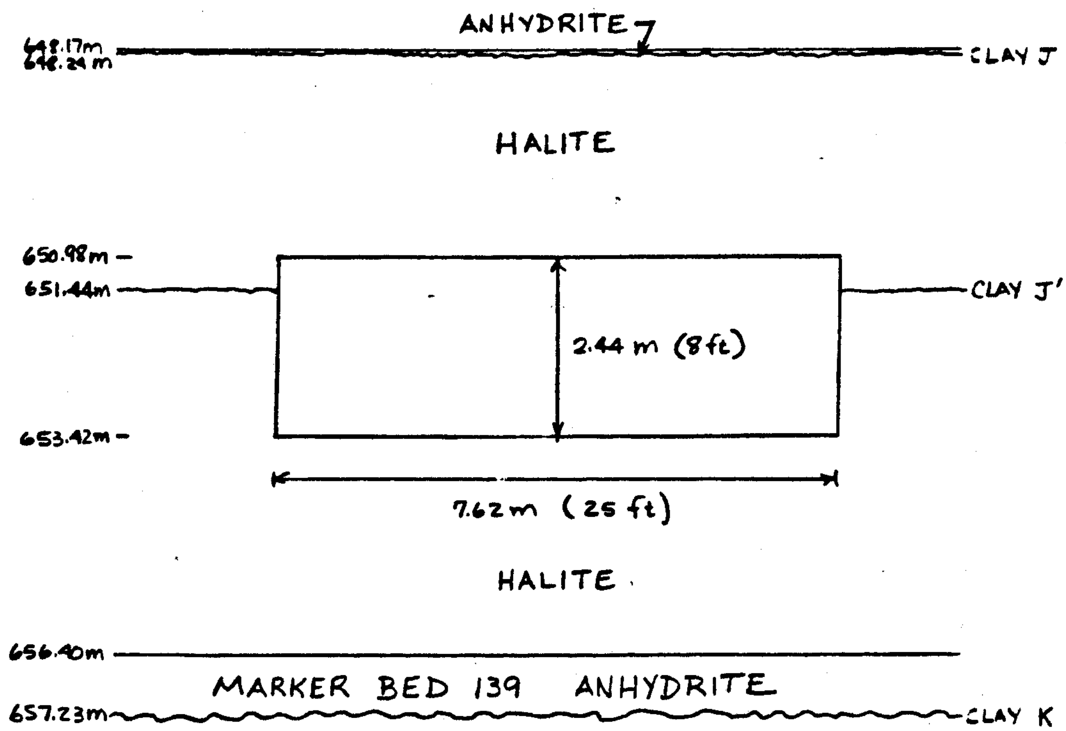

Figure 4. Cross Section of South Drift Geometry.

Copy to:
1500 W. Herrmann
1510 J. W. Nunziato
1520 D. J. McCloskey
1521 R. D. Krieg
1521 H. S. Morgan
1521 D. C. Preece
1521 C. M. Stone
1521 D. M. Webb
1522 R. C. Reuter
1522 R. M. Russo
1523 J. H. Biffle
1523 J. D. Miller
1524 W. N. Sullivan
1524 L. J. Branstetter
1530 L. W. Davison
1540 C. M. Luth
1542 B. M. Butcher
1542 D. J. Holcomb
1542 L. W. Teufel
1542 W. R. Wawersik
1542 D. H. Zeuch
6310 T. O. Hunter
6330 W. D. Weart
6331 A. R. Lappin
Attn: D. J. Borns
6332 L. D. Tyler
6332 R. V. Matalucci