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APPENDIX C
FLAC MODELING OF THE PANEL CLOSURE SYSTEM

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Numerical modeling is considered one of the better methods available for quantifying the interaction of concrete barriers with the surrounding media. Therefore, a series of models have been developed for this report to evaluate the interaction of the main concrete barrier of the panel closure system with the surrounding salt for different alternatives and concrete barrier geometries. This appendix discusses the code used and describes the material constitutive models used in the stress analysis.

C.1.0 The FLAC Code

FLAC software has been used for numerical modeling of the underground excavations at the WIPP since 1991. FLAC is a two-dimensional explicit finite difference code that simulates the behavior of rock and soil-like structures. The WIPP Reference Creep Law is built into FLAC and has been verified to Nuclear Regulatory Commission standards (Itasca, 1995). In addition, all versions of FLAC used by the Westinghouse Waste Isolation Division have been verified against the WIPP Second Benchmark Problem (Krieg, 1984).

C.2.0 Material Constitutive Models

The material properties associated with the material constitutive models are given in Tables C-1 through C-3. These properties are the standard properties which have been used in previous WIPP geotechnical FLAC modeling such as the Backfill Engineering Analysis Report (BEAR) (IT, 1994). Note that the stress analysis of the concrete barrier also uses the same stress-strain relationship for the uncompacted crushed salt as was used in the BEAR. The stress analysis in Figure 4-4 used uncompacted crushed salt on one side of the enlarged concrete barrier and open void space on the other side. The crushed salt has subsequently been eliminated from the panel closure system final design. The symmetry in the principal stress plots for the enlarged concrete barrier analysis indicated that the presence or absence of the crushed salt does not significantly affect the stresses within the enlarged concrete barrier. Therefore, the FLAC analysis results presented in Figure 4-4 apply to the panel closure system final design.

Table C-1[a]
FLAC[b] Model Time-Dependent Material Properties

Property	Halite	Argillaceous Halite	Halite, 10% Polyhalite
Bulk modulus (GPa)	20.7	20.7	22.1
Shear modulus (GPa)	12.4	12.4	13.2
Density (kg/m^3)	2,300	2,300	2,300
Activation energy (cal/mol)	12,000	12,000	12,000
A	4.56	4.56	4.56
B	127	127	127
D (Pa$^{-4.9}$/s)	5.79×10^{-36}	1.74×10^{-35}	5.21×10^{-36}
n	4.9	4.9	4.9
Gas constant (cal/mol K)	1.987	1.987	1.987
Critical strain rate	5.39×10^{-8}	5.39×10^{-8}	5.39×10^{-8}

Table C-2[a]
FLAC[b] Elastic Material Properties

Property	Anhydrite	Polyhalite	Concrete
Bulk modulus (GPa)	83.4	65.8	11.6
Shear modulus (GPa)	27.8	20.3	9.0
Density (kg/m^3)	2,300	2,300	2320
Cohesion (MPa)	27	17.2	–
Friction (degrees)	29	46.5	–

Table C-3[a]
FLAC[b] Clay Seam Material Properties

Property	Value
Normal stiffness (Pa/m)	1.0×10^{12}
Shear stiffness (Pa/m)	5.0×10^{10}
Cohesion (Pa)	0.0
Friction (degrees)	5

[a]IT, 1994

[b]FLAC = Fast Lagrangian Analysis of Continua
GPa = Gigapascal(s)
kg/m^3 = Kilogram(s) per cubic meter
cal/mol = Calorie(s) per mole
Pa$^{-4.9}$/s = Pascal(s) to the negative 4.9 per second
cal/mol K = Calorie(s) per mole Kelvin
A,B,n = unitless model factors
D = model factor
Pa/m = Pascal(s) per meter
MPa = Megapascal(s)

C.3.0 References

IT Corporation (IT), 1994, "Backfill Engineering Analysis Report," report prepared for Westinghouse Electric Corporation, Carlsbad, New Mexico.

Itasca Consulting Group, Inc. (Itasca), 1995, "FLAC User's Manual," Itasca Consulting Group, Inc., Minneapolis, Minnesota.

Krieg, R. D., 1984, "Reference Stratigraphy and Rock Properties for the Waste Isolation Pilot Plant," *SAND83-1908*, Sandia National Laboratories, Albuquerque, New Mexico.