SAND2015-11078C

Geomechanical Considerations for the Deep Borehole Field Test

H11B-1323 Byoung Yoon Park[1] and Kristopher L. Kuhlman[2]

Sandia National Laboratories [1]Geomechanics and [2]Applied Systems Analysis & Research Departments Albuquerque, NM 87185, USA [1]bypark@sandia.gov

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Abstract

Deep borehole disposal of high-level radioactive waste is under consideration as a potential alternative to shallower mined repositories. The disposal concept consists of drilling a borehole into crystalline basement rocks to a depth of 5 km, emplacement of canisters containing solid waste in the lower 2 km, and plugging and sealing the upper 3 km of the borehole. Crystalline rocks such as granites are particularly attractive for borehole emplacement because of their low permeability and porosity at depth, and high mechanical strength to resist borehole deformation. In addition, high overburden pressures contribute to sealing of some of the fractures that provide transport pathways. A numerical model will be constructed to predict the geomechanical considerations (e.g., borehole breakouts and disturbed rock zone development). Kayenta constitutive model (Figure 2) will be used to represent the crystalline rock behavior. Parameters needed in the simulation are listed to show how to obtain from laboratory and field.

Deep Borehole Disposal Concept

Deep borehole disposal of high-level radioactive waste has been considered as an option for geological isolation for many years, including original evaluations by the U.S. National Academy of Sciences in 1957. As shown in Figure 1, waste in the deep borehole disposal system is several times deeper than for typical mined repositories, resulting in greater natural isolation from the surface and near-surface environment. The disposal zone in a single borehole could contain about 400 waste canisters of approximately 5 m length. The borehole seal system would consist of alternating layers of compacted bentonite clay and concrete [Arnold et al., 2011].

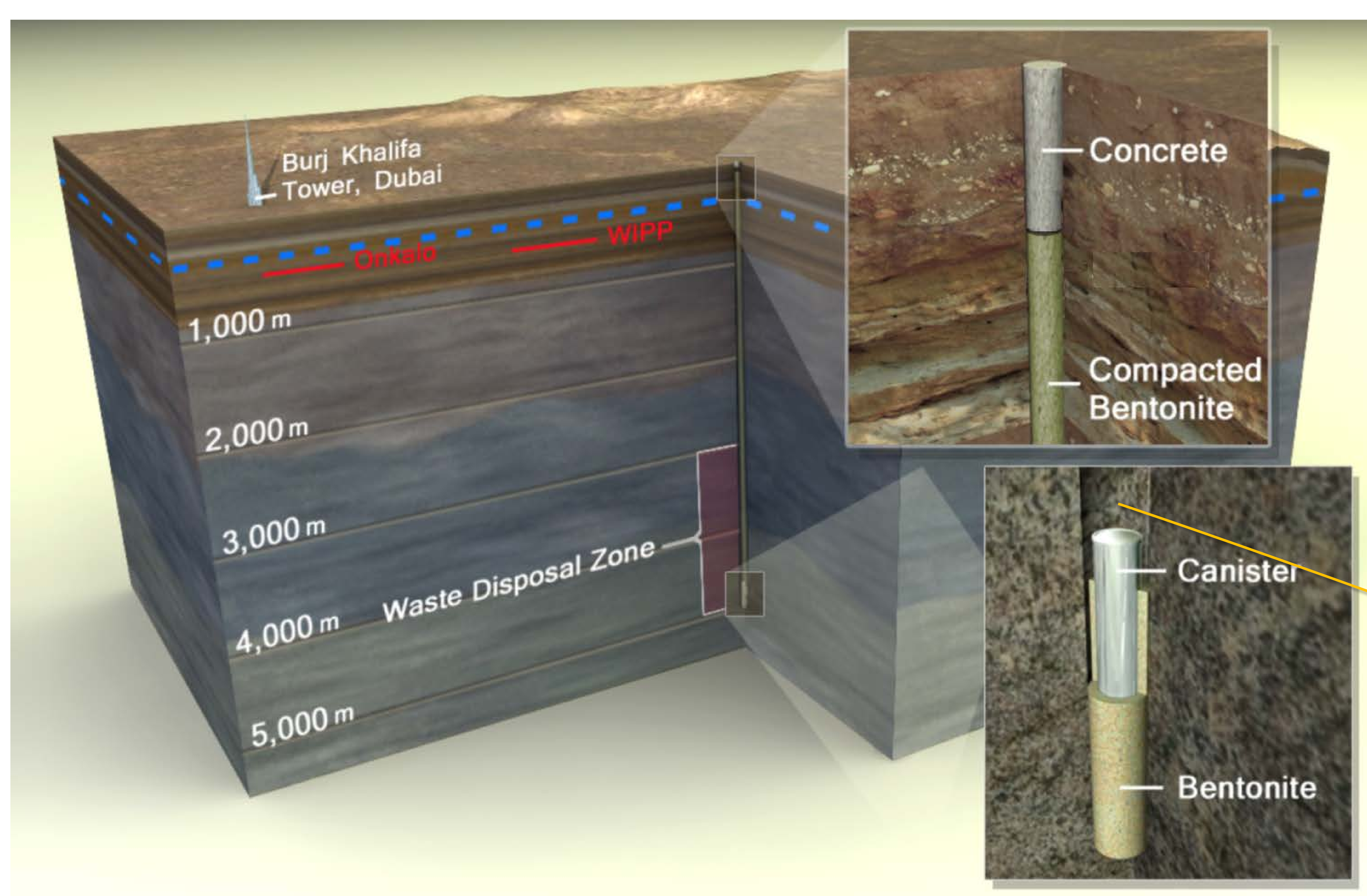


Figure 1. Generalized concept for deep borehole disposal of high-level radioactive waste [Arnold et al., 2011]

References

Arnold, B.W., P.V. Brady, S.J. Bauer, C.G. Herrick, S. Pye, and J. Finger (2011) *Reference Design and Operations for Deep Borehole Disposal of High- Level Radioactive Waste*, SAND2011-6749, Sandia National Laboratories, Albuquerque, New Mexico.

Brannon, R.M., T.J. Fuller, O.E. Strack, A.F. Fossum, and J.A. Sanchez (2009) *KAYENTA: Theory and User's Guide*, SAND2009-2282, Sandia National Laboratories, Albuquerque, New Mexico.

Kayenta Constitutive Model

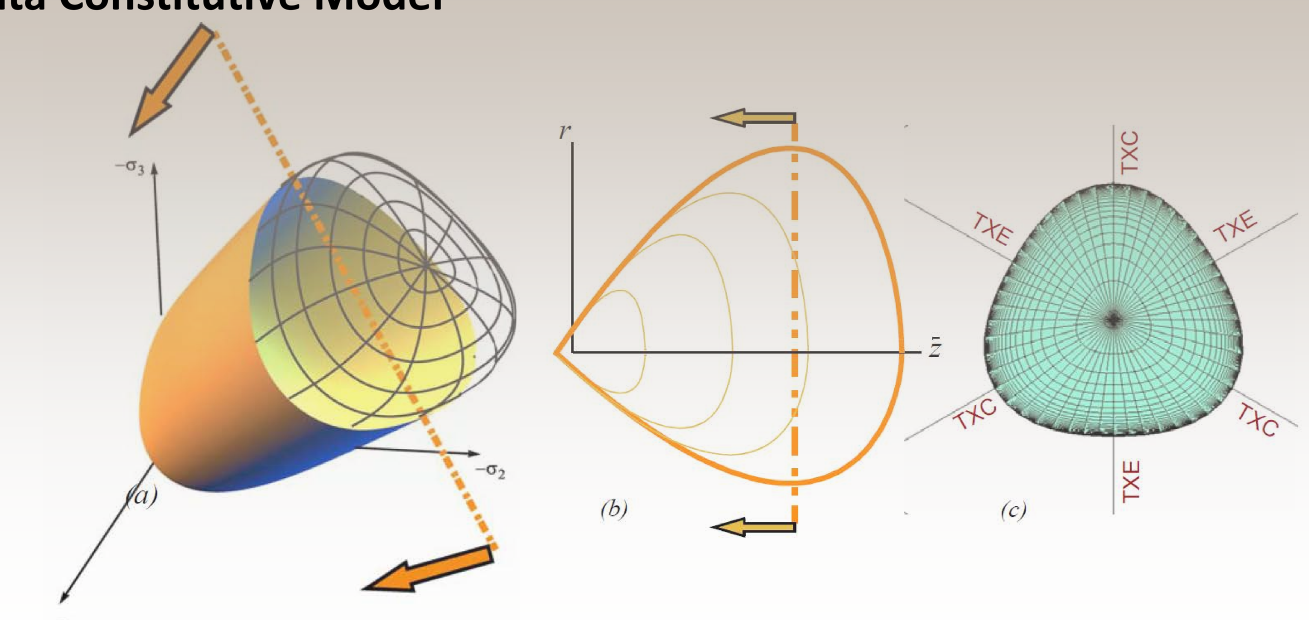
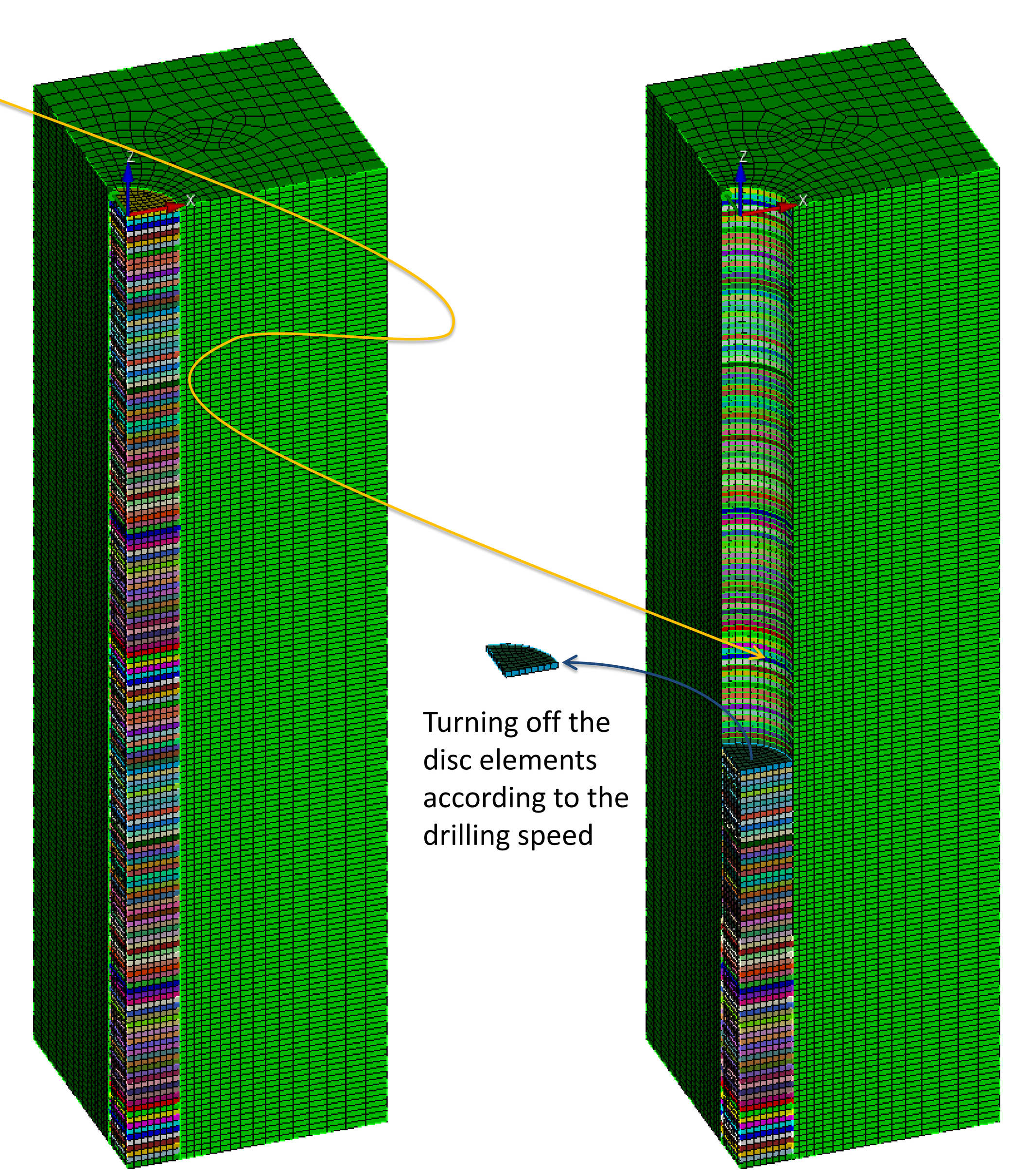


Figure 2. Kayenta continuous yield surface. **(a) three-dimensional view** in principal stress space with the high pressure "cap" shown as a wire frame, **(b) the meridional "side" view** (thick line) with the cap shown on the more compressive right-hand side of the plot using cylindrical coordinates in which $\bar{z}$ points along the compressive direction, and **(c) the octahedral view**, which corresponds to looking down the hydrostat (onto planes perpendicular to the direction); an option is available for a pressure-varying octahedral profile. [Brannon et al., 2009]

- Mathematically, Kayenta is a generalized plasticity model
  - The material response is elastic whenever the stress is on the inside of the yield surface
  - If continuing to apply elasticity theory would move the stress into regions outside the yield surface, the plasticity equations are applied
- Yield Function: $f(\boldsymbol{\sigma}, \boldsymbol{\alpha}, \kappa) = J_2\Gamma^2(\bar{\theta}) - [F_f(I_1) - N]^2 F_c(I_1, \kappa)$
  - $\boldsymbol{\sigma}$ = stress tensor, $\boldsymbol{\alpha}$ = backstress tensor
  - I_1 = first stress invariant, J_2 = second stress invariant
  - F_f and Γ are used to describe the elastic limit caused by the presence of microcracks.
  - F_c accounts for strength reduction by porosity. It depends on an internal state variable κ whose value controls the hydrostatic elastic limit.
  - N = material parameter which characterizes the maximum allowed translation of the yield surface when kinematic hardening is enable.
  - $\Gamma(\bar{\theta})$ accounts the differences in material strength in triaxial extension and compression using Lode angle $\bar{\theta}$.



Numerical Simulation

- SIERRA Adagio* mechanics codes will be used for quasi-static behavior for long-term
- Kayenta constitutive model (Figure 2) will be used for the host rock behavior. The related material properties will be obtained as listed in Table 1.
- A mesh containing element layers (disc shape with inch thickness) in the hole around the concerning depth, and turning off the disc elements according to the drilling rate
- Borehole breakouts and disturbed rock zone development will be predicted

* Adagio is the most recently SNL-developed 3D solid mechanics code. It is written for parallel computing environments.

Table 1. Material parameters of crystalline rock used in the analysis and tests to obtain

	Name	Symbol	Lab. Test	Field Test
General	• In-situ stresses	σ_H, σ_h σ_v		- Hydraulic fracturing
	• Density	ρ	- Core measurement	
	• Young's modulus	E	- Uniaxial compression	
	• Poisson's ratio	ν	- Uniaxial compression	
	• Bulk modulus	K	- Hydrostatic test	
	• Lamé modulus	λ	- Calculated from other moduli	
	• Shear modulus	G	- Constant mean stress triaxial test	
Crystalline rock in Kayenta	• Initial elastic bulk modulus	b_0	- Hydrostatic test	
	• High pressure coefficient	b_1	- Hydrostatic test	
	• Curvature parameter	b_2	- Hydrostatic test	
	• Initial elastic shear modulus	g_0	- Constant mean stress triaxial test	
	• Joint spacing			- Outcrop exploration - Borehole televiewer
	• Joint shear stiffness		- Triaxial compression/direct shear test	
	• Joint normal stiffness		- Triaxial compression/direct shear test	
	• Constant of vertical intercept	a_1	- Triaxial compression test	
	• Curvature decay parameter	a_2	- Triaxial compression test	
	• Parameter in the shear limit meridional fit function	a_3	- Triaxial compression test	
	• High pressure meridional slope parameter in the fit function	a_4	- Triaxial compression test	
	• Value of I_1 at the onset of pore collapse for hydrostatic compression of virgin material	p_0	- Fitting constant from hydrostatic test	
	• One third of the slope of a porosity vs pressure crush curve at the elastic limit	p_1	- Fitting constant from hydrostatic test	
	• Extra fitting parameter for hydrostatic crush curve data, used when the crush curve has an inflection point	p_2	- Fitting constant from hydrostatic test	
	• Asymptote (limit) value of the absolute value of the plastic volume strain	p_3	- Fitting constant from hydrostatic test	
	• Shape parameter that allows porosity to affect shear strength	R	- User-specified constant	
	• TXE/TXC (tri-axial extension to compression) strength ratio	ψ	- Triaxial compression test - Triaxial extension test	
	• Off-set parameter	N	- User-specified shift parameter	
	• Kinematic hardening parameter	H	- Uniaxial test	
	• Tensile cut-off in allowable value of the first stress invariant I_1	I_1^{cut}	- User-specified constant	
	• Principal stress tensile cut-off		- User-specified constant	
	• Integer-valued control parameter for specifying the desired type of 3rd-invariant yield surface		- User-specified constant	

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND No. 2011-XXXXP