U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Mechanical Degradation of the Drip Shield

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Mark Board
Itasca Consulting Group

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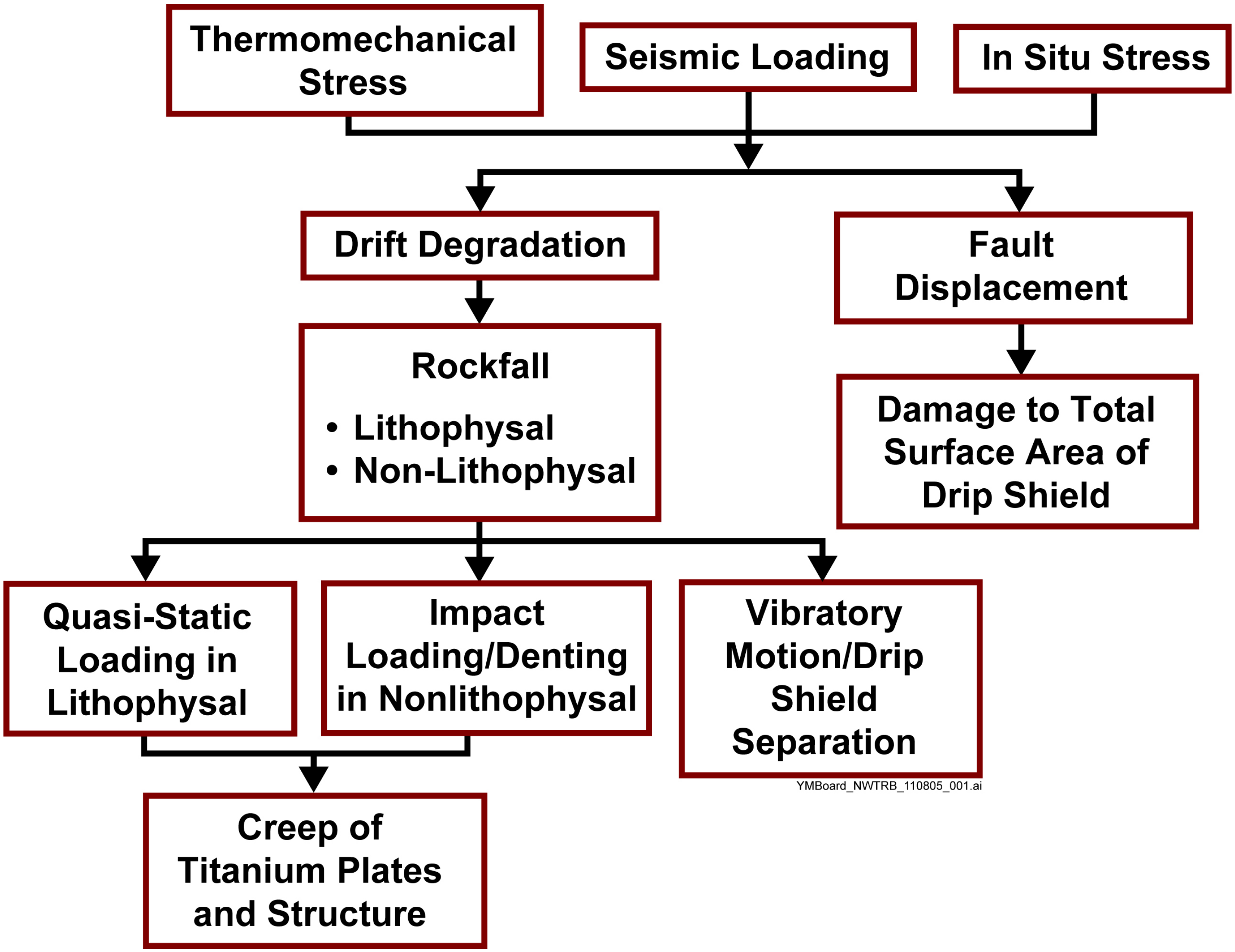
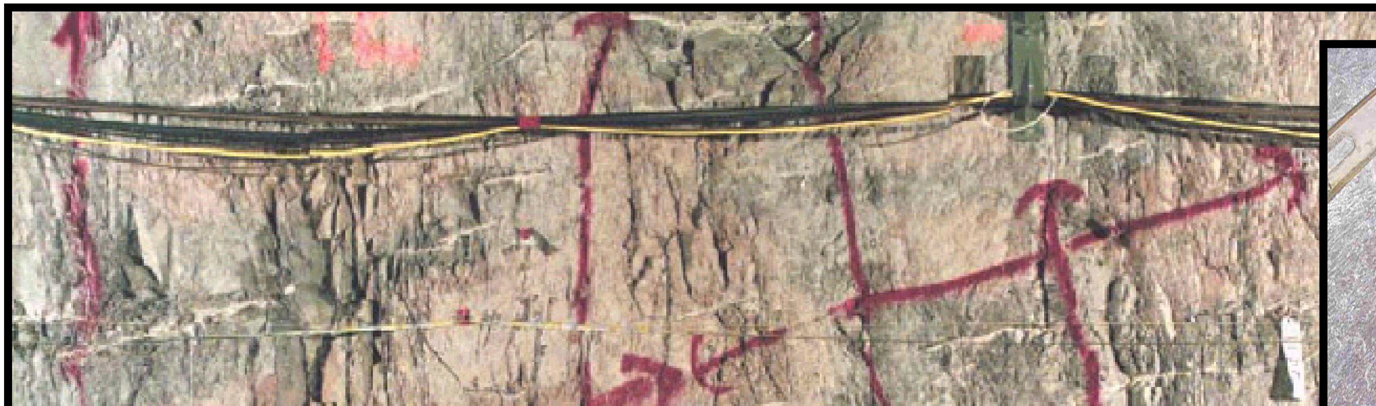
Las Vegas, NV

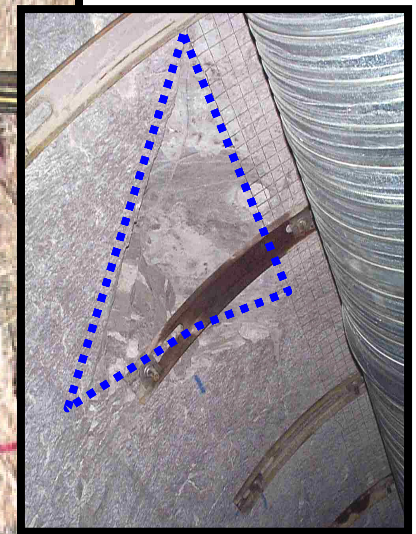
Objectives

- Describe the various sources of mechanical degradation of the drip shield
- Review emplacement drift degradation under vibratory motion and possible long-term rock mass strength degradation
- Review drip shield structural response to quasi-static loading from rubble generated by drift collapse
- Review drip shield structural response to impact from large rock blocks
- Review drip shield structural response to vibratory motion from seismic events

Mechanical Degradation Mechanisms







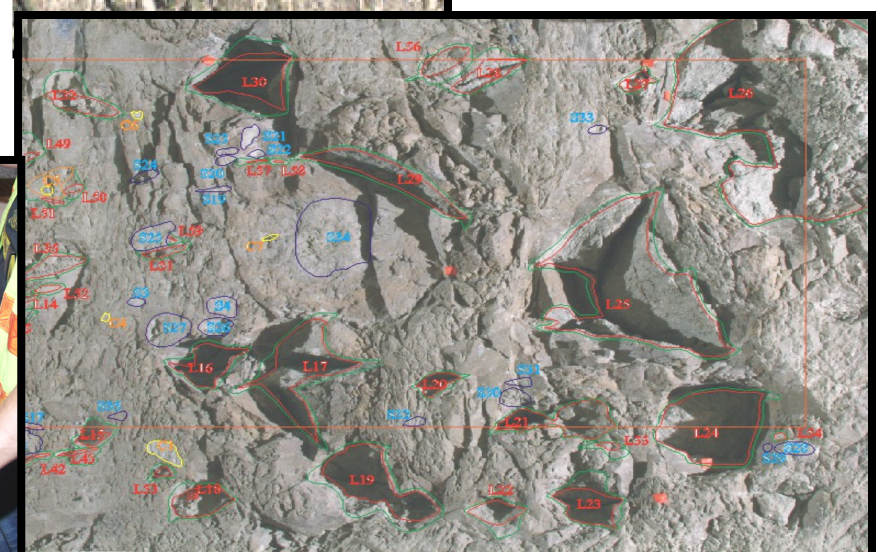
Non-Lithophysal Rock:

Discontinuous, distinct fracture sets ~ 15% of emplacement area

Vs

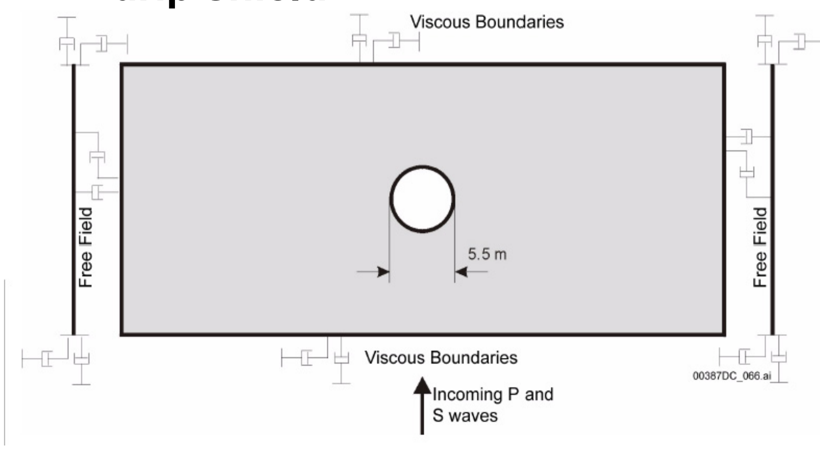
Lithophysal Rock:

short, rough, ubiquitous fractures with irregular cavities ~ 85% of emplacement area

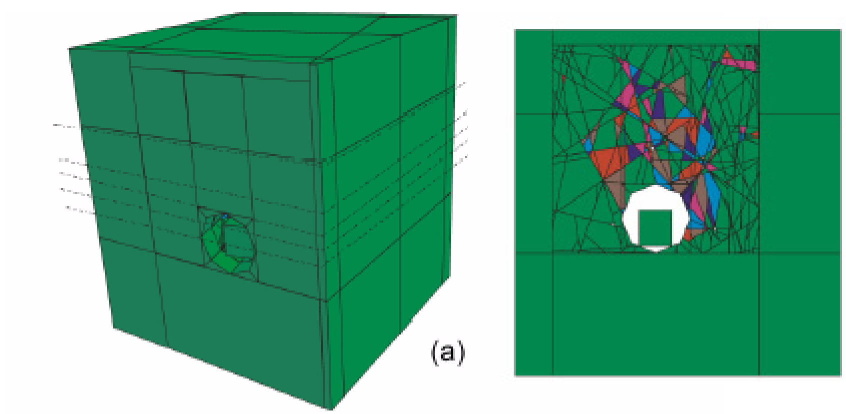


Drift Degradation Under Dynamic Loading and Long-Term Strength Degradation

- **Dynamic sensitivity analyses of drift degradation conducted for a range of ground motion time histories (15) representative of 0.384, 1.05, 2.44 and 5.35 m/s peak ground velocity (PGV) levels and for a range of rock properties and in situ rock fracture geometries**
- **Although an analysis is performed at the 5.35 m/s PGV level, PGV level is bounded at 4 m/s for TSPA based on geologic observations of lack of failure in lithophysal cavities *(Peak Ground Velocities for Seismic Events at Yucca Mountain, Nevada)***
- **Rockfall block total volume, shape, mass, velocity (energy), and impact location distributions determined from the models**
- **Total drift collapse is representative of possible long-term rock mass strength degradation and defines potential non-uniform, quasi-static loading distribution to drip shield**

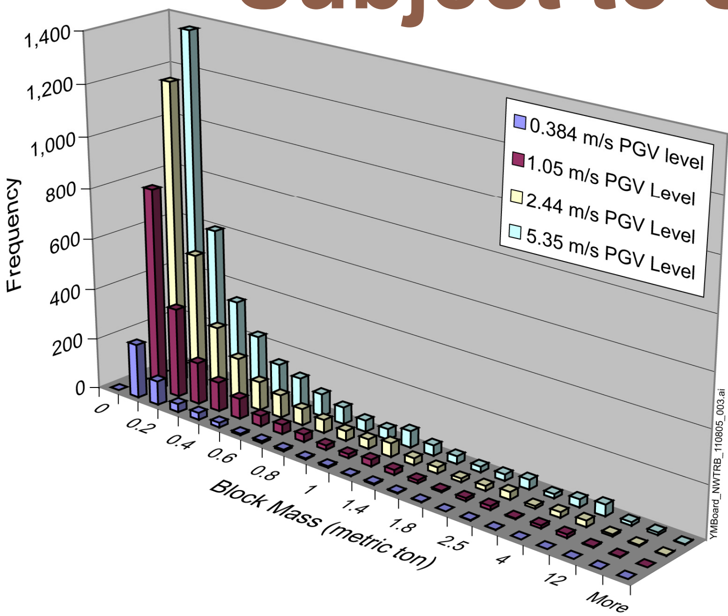


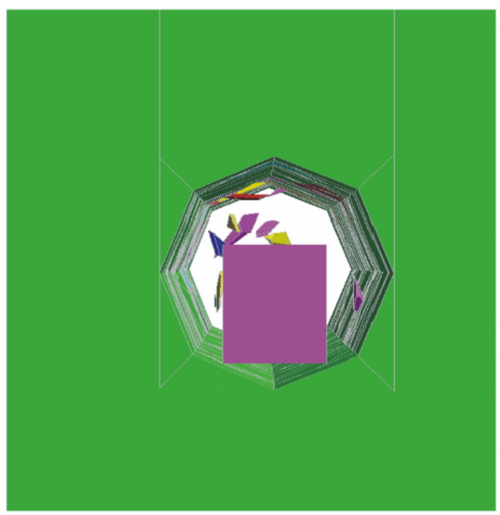
2D Lithophysal Discontinuum Model



3D Non-lithophysal Discontinuum Model

Drift Degradation in Non-Lithophysal Rock Subject to Seismic Loading

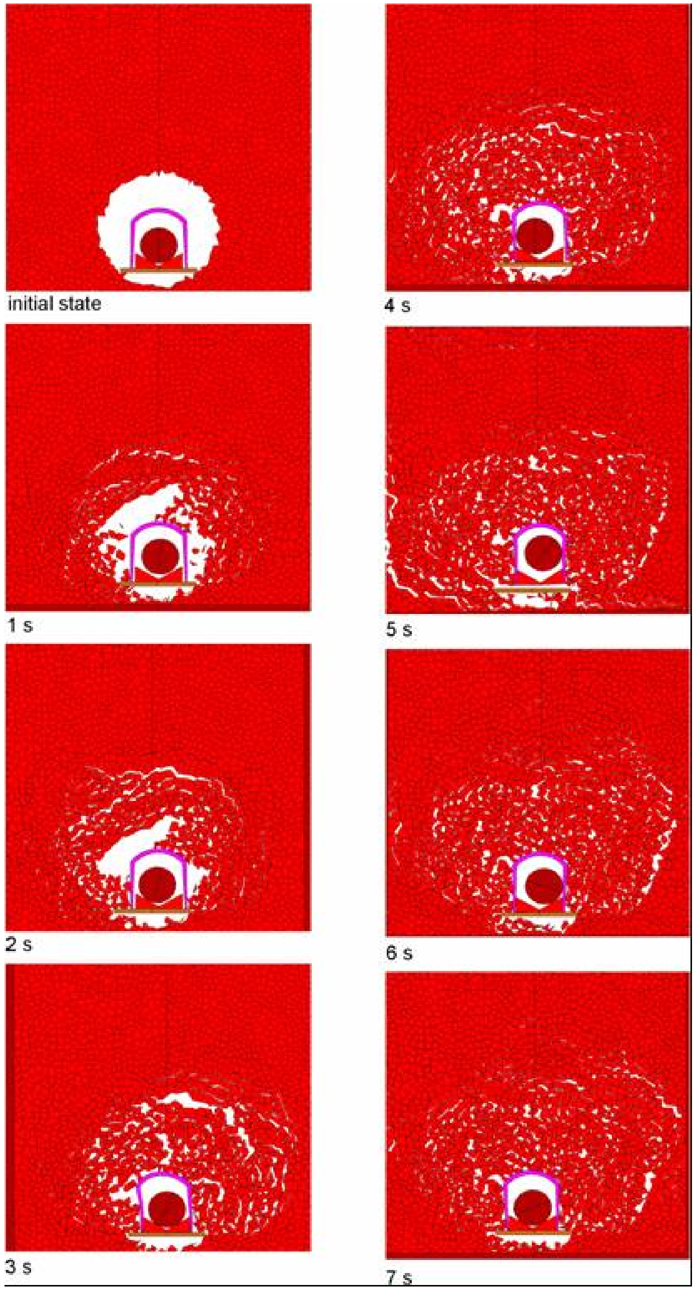




- **Rockfall occurs at 0.384, 1.05, 2.44 and 5.35 m/s PGV levels**
- **Rockfall shapes and sizes controlled by pre-existing cooling fractures**
- **Distribution of dislodged block masses derived from modeling shows a negative-exponential form with median block size of approximately 0.15 metric ton (MT)**

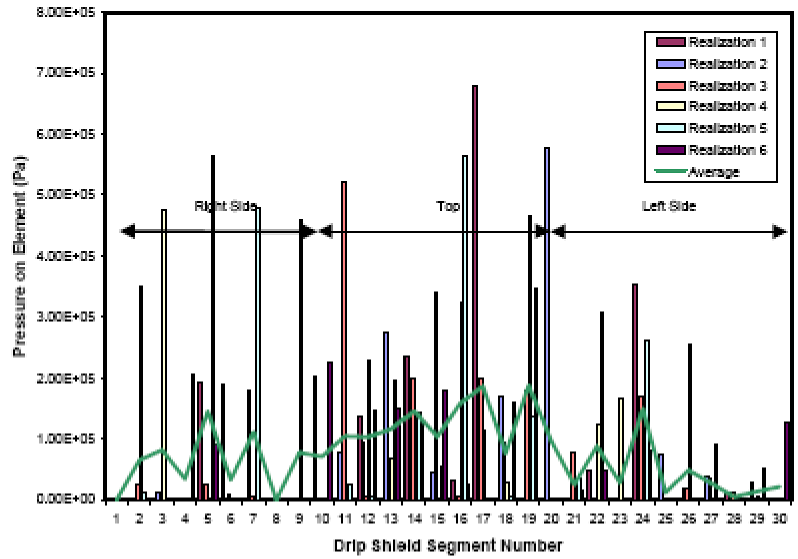
Drift Degradation in Lithophysal Rock Subject to Seismic Loading

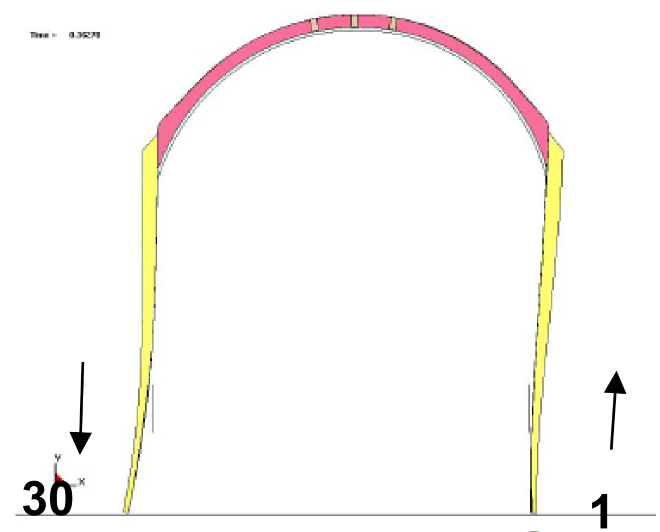
- **Model predicts partial collapse in lithophysal rocks for PGV levels greater than about 1 m/s and complete collapse for PGV levels greater than approximately 2 m/s**
- **Collapse occurs within seconds of the arrival of strong ground motion, "pinning" drip shield to invert prior to significant motion of drip shield**
- **Figure shows example of greatest damage to drift in lithophysal rock at the 2.44 m/s PGV level**



Drip Shield Response to Quasi-Static Loading from Long-Term Lithophysal Drift Collapse

- **Examined 6 cases of complete drift collapse in lithophysal rock using 2D discontinuum simulation approach**
- **Determined non-uniform loading on the drip shield (see Figure at right)**
- **Applied non-uniform loads to LS-DYNA structural calculation**
- **Drip shield stable under all quasi-static load combinations**
- **Increased loads to explore safety margin – estimated to be approximately 300%**



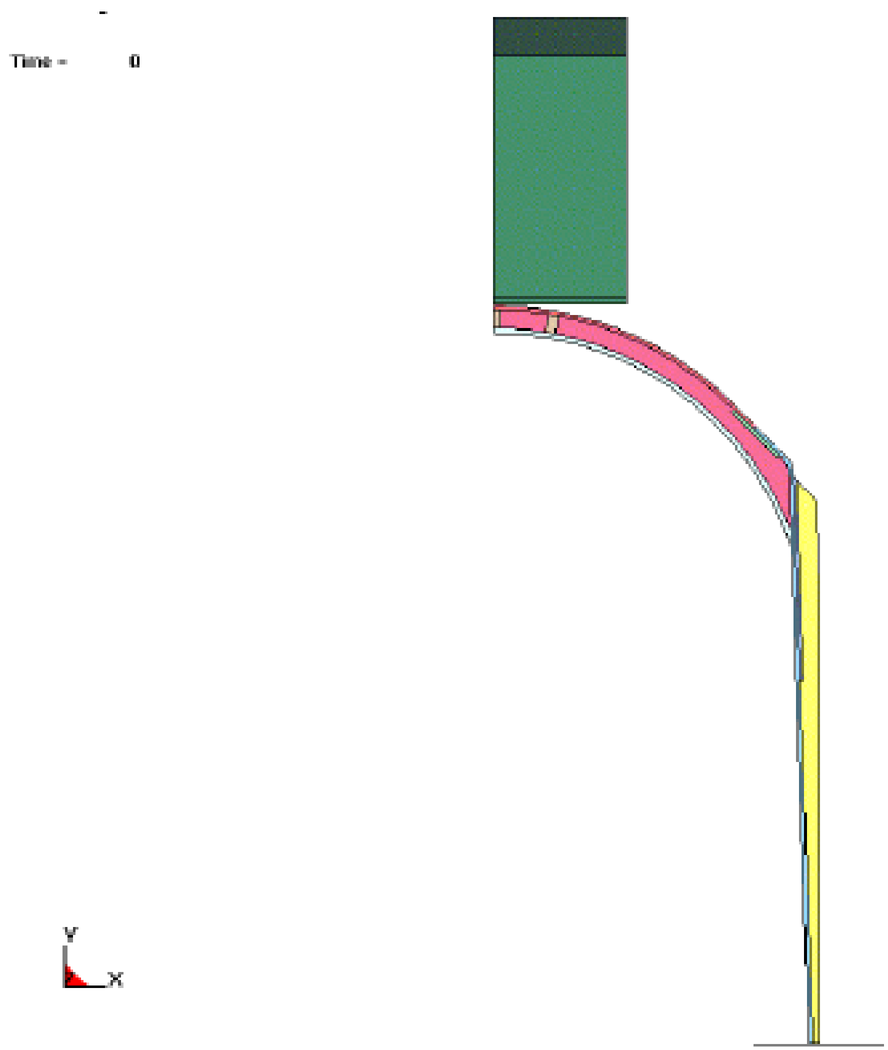


Drip Shield Response to Seismic Effects

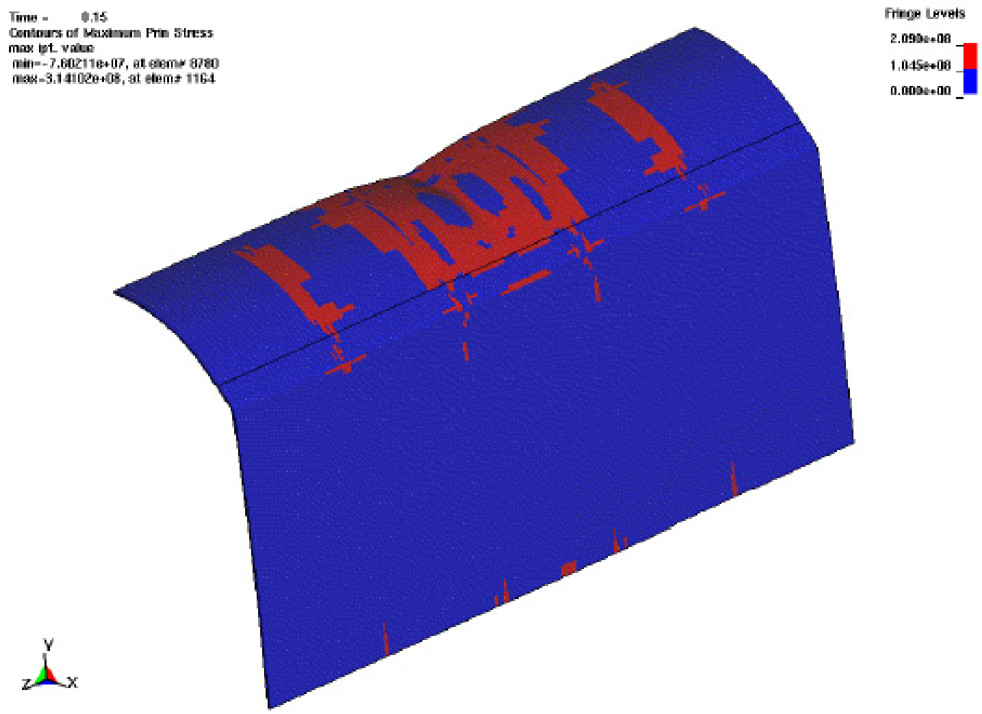
- **Three degradation mechanisms:**
  - **Potential structural damage from impact of large rock blocks**
  - **Potential drip shield separation**
  - **Fault displacement**
    - **Can occur as a result of seismic events with annual frequencies lower than 2 x 10^{-7} per year**
    - **Damage is modeled as total loss of drip shield functionality for a small number of drip shields (less than 60)**

Mechanical Impact from Rockfall

- Dynamic impact from rock blocks only considered for emplacement drifts in nonlithophysal rock
- Rock block masses, velocities and impact locations generated during seismic events in non-lithophysal drifts sampled for 2.44 and 5.35 m/s PGV levels
- Dynamic impact analyses with LS-DYNA represent a range of rock block impact energies and locations from the 2.44 and 5.35 m/s PGV levels
  - 50th to 95th percentile of block energies
  - Impact at various locations (top, corner, side)



Summary of Rock Impact Results

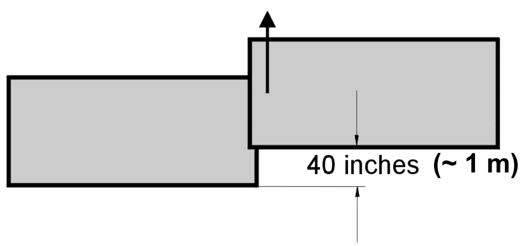


Deformed Shape and Damaged Surface Area for Impact of Largest Impact Energy Block (28 MT)

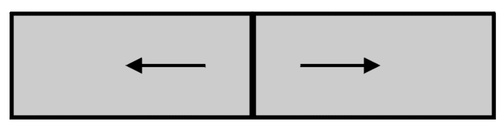
- **Structure remains stable after impact by even the greatest energy block**
- **Estimated surface damaged area (Residual tensile stress exceeds 50% of Ti-7 yield strength) – up to approximately 15% of the surface area for impact of largest block**
- **Depth and volume of dents that can pool water are small (max deflection for 28 metric ton (MT) block is approx. 0.1 m, but depth of dent that can pool water is less than 5 mm)**
- **A significant volume of water does not pool in the dents**
  - **Static head is required to drive advective flux through the resulting stress corrosion cracks**

Drip Shield Separation During Vibratory Motion

- Drip shields are interlocked together forming a chain resting on the invert
- Drip shields can be separated if
  - Vertical displacement of one drip shield relative to another is greater than approximately 40 inches

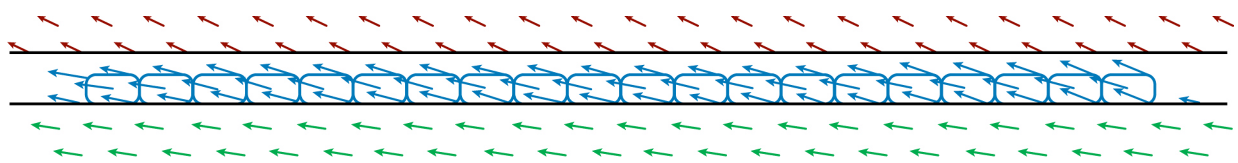


  - Axial force is sufficient to shear off the welds on the drip shield connector interlocking bars



Motion of the Invert under Vibratory Motion

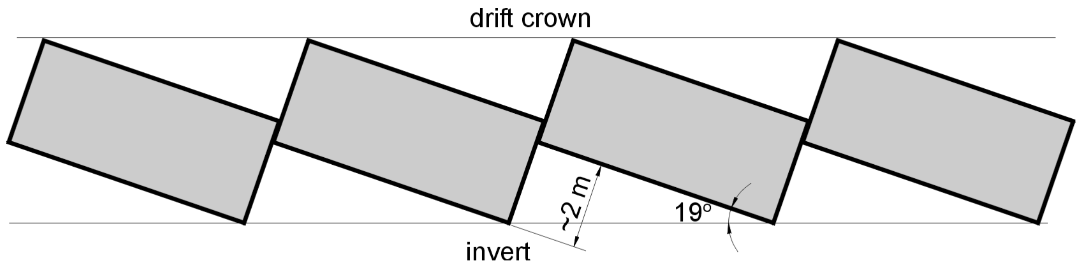
- Seismically-induced motion of the invert along the entire drip shield chain (approximately 600 m long) will be practically synchronous
  - Incoming seismic waves are almost vertically incident (at most 10-15 degrees off vertical incidence)
  - Dominant frequencies of the incoming seismic waves have relatively long wavelengths (>1.5 km)



- If conditions along the drift are uniform, the incoming seismic wave will not cause traveling wave along the drip shield chain (i.e., all drip shields will move synchronously)

Analysis of Drip Shield Separation

- Separation potentially possible as a result of rotation or differential motion of the drip shields or shearing of the connector bar welds



- Differential motion can be caused by variation of interaction between the drip shield and the invert (i.e., friction) or partial rockfall along the drift
- Extensive 2D kinematic (discontinuum) and 3D structural analysis of vibratory motion and movement of a chain of drip shields
  - Analyzed effect of 15 different ground motions for 1.05, 2.44 and 5.35 m/s PGV Levels
  - Analyzed effect of randomly varying metal to rock and metal to metal friction angles over wide range
  - Analyzed impact of partial and complete drift collapse on drip shield (DS) kinematics
- Rubble from partial or complete drift collapse lying against or covering drip shields damps differential motion and rotation, preventing separation. Drift collapse or partial collapse occurs at PGV levels less than that required to induce separation in an open drift.

Conclusions

- Rock mass loading to drip shield was estimated using discontinuum analysis approach that yields realistic, highly non-uniform load distributions. Impact of rock lithology present in repository horizon taken into account in rockfall calculations.
- Drip shield is structurally stable under quasi-static loading from long-term strength degradation and collapse of the emplacement drifts
- Impact loading from the largest and most highly-energetic blocks examined. Drip shields are structurally stable and estimated dent depths determined.
- Drip shield separation examined for full range of seismic shaking. Rubble from drift degradation prevents drip shield separation through frictional restraint or weight applied to the interlocked drip shield chain.
- Small number of drip shield failures from fault displacement resulting from seismic events with annual frequencies lower than 2×10^{-7} per year

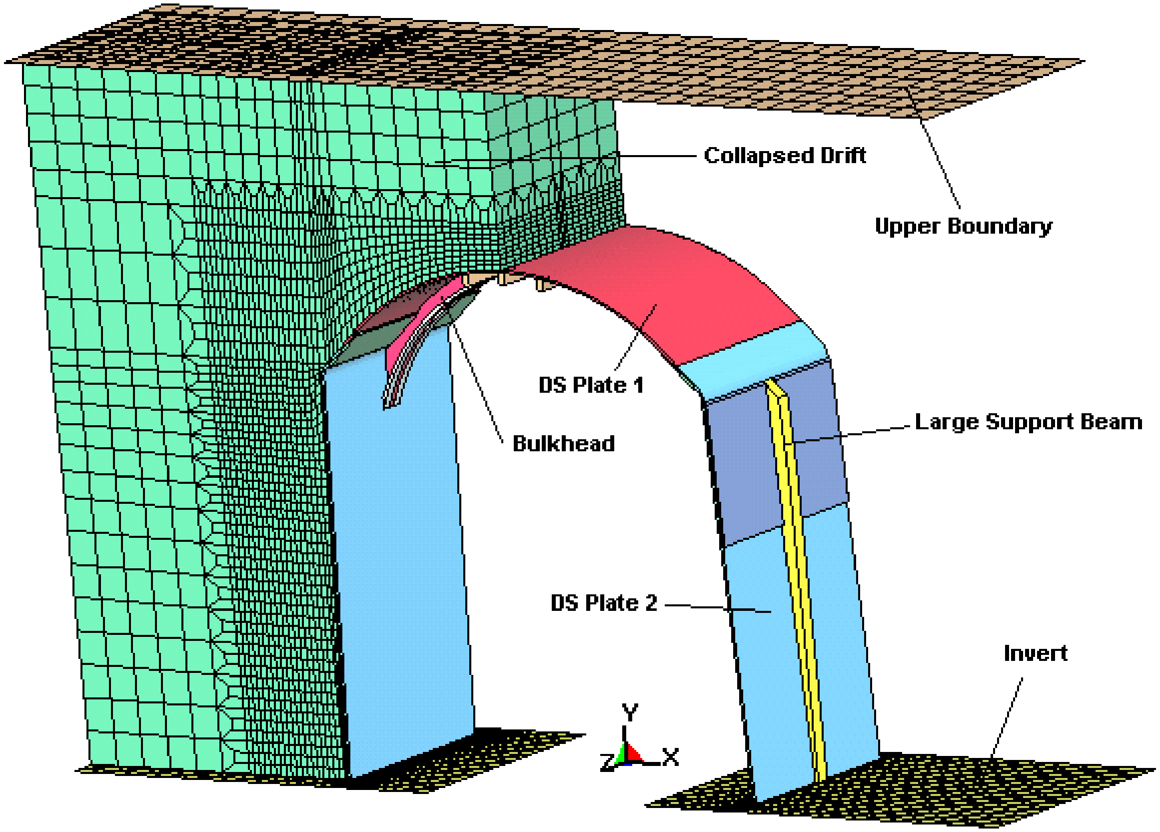
Waste Package and Drip Shield Failure Due to Fault Displacement

Annual Exceedance Probability, λ (1/yr)	Expected Number of Waste Package and Drip Shield Failures				
	PWR	BWR	Naval	HLW	Total
$> 2 \times 10^{-7}$	0	0	0	0	0
1×10^{-7} to 2×10^{-7}	0	0	0	5.64	5.64
5×10^{-8} to 1×10^{-7}	0	0	0.61	5.64	6.25
3×10^{-8} to 5×10^{-8}	8.40	5.35	0.61	6.20	20.56
2×10^{-8} to 3×10^{-8}	8.40	5.35	0.67	6.20	20.62
1×10^{-8} to 2×10^{-8}	9.24	5.89	0.67	39.98	55.78

Source: DTN: MO0508SPACOMPA.002 [DIRS 175229]

From: Seismic Consequence Abstraction (2005)

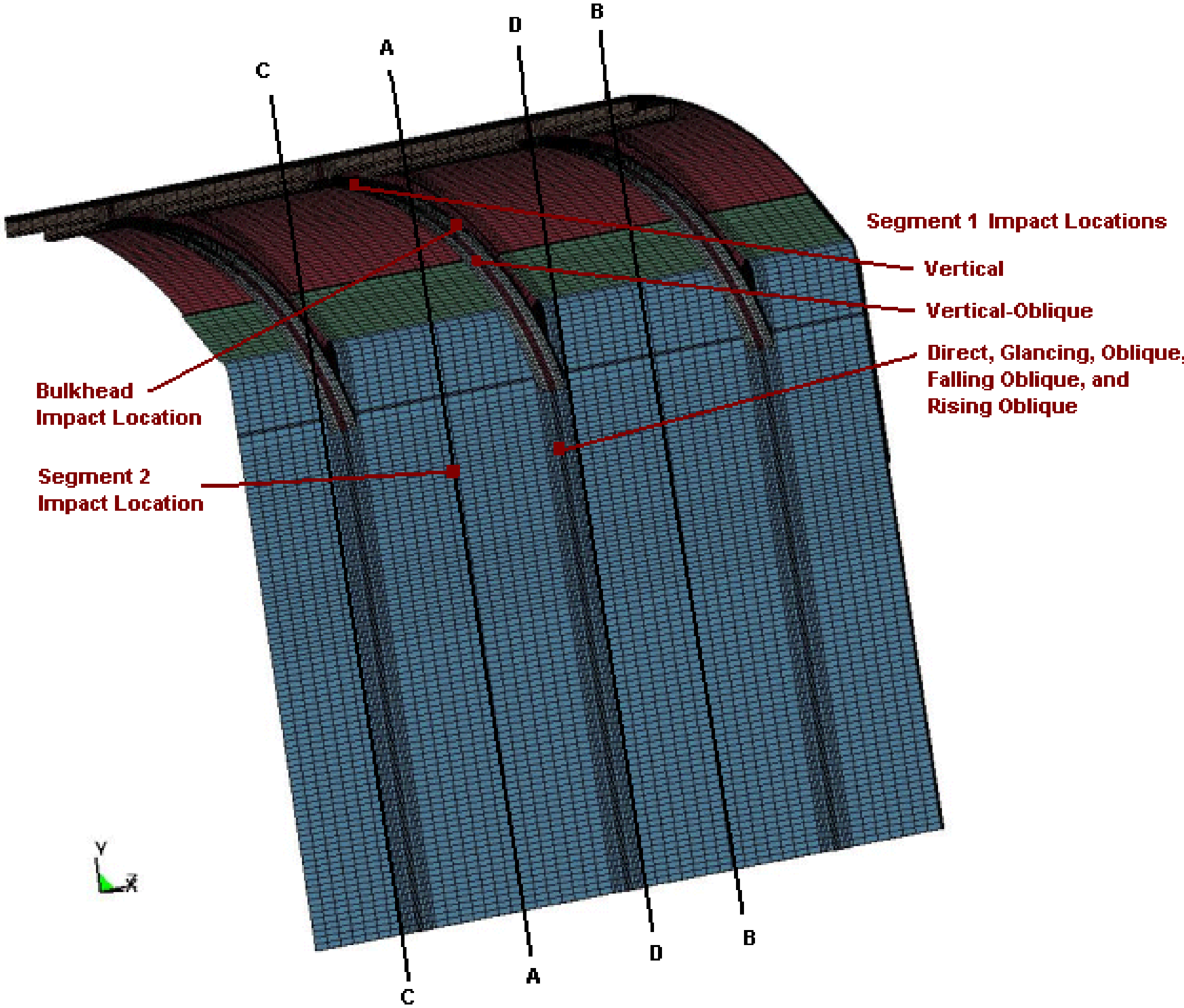
Waste Package Impacts to the Drip Shield



- **Models include representation of the collapsed drift surrounding the drip shield**
- **Segments of the drip shield are used to reduce the computational time**

- **Drip shield response to location of impact, direction of impact, and WP orientation were explored in parametric analyses (impact velocity = 6 m/s for all cases)**
- **Extreme possibilities such as high impact velocities, multiple impacts and longitudinal impacts to the bulkhead were also considered**

Waste Package Impacts to the Drip Shield



- The drip shield remains stable through all impact scenarios
- From the parametric analyses, vertical and vertical-oblique impacts cause the highest stresses and side displacements
- For a given velocity, longitudinal impacts to the bulkhead are the most severe

- Longitudinal impacts to the bulkhead are limited due to the specific alignment and motion of the waste package necessary for the edge of the waste package to contact the side of the bulkhead