U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Response of the Waste Package Emplacement Pallets and Drip Shields to Seismic Events

Presented to:
Nuclear Waste Technical Review Board
Joint Meeting of the Natural System and Engineered System Panels

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Topics for Discussion

- **Post-closure Vibratory Ground Motion**
  – **Assumptions, analysis inputs and methodology**
  – **Problem domain division**
  – **Finite element analysis (FEA) representations**
  – **Results to date**
- **Post-closure Rock Fall Impact**
  – **Assumptions, analysis inputs and methodology**
  – **Finite element analysis representations**
  – **Results to date**
- **Summary**

Assumptions for Vibratory Ground Motion

- Strong-motion duration and wave phasing is represented by the use of acceleration time histories
  - Duration captures 5% - 95% of total energy content
  - Deformation process is adequately represented
  - Durations of ground motion time histories are approximately 15-30 seconds
- Deformation is localized within contact region
  - Some portions of the problem may be represented as rigid, as appropriate

Vibratory Ground Motion Inputs and Methodology

- **Uncertain parameters**
  - Acceleration time histories for a given peak ground velocity (PGV)
    - 15 time histories per annual frequency level
  - Friction coefficients
    - Relatively small sample size (approximately 15)
    - Sampling from uniform probability distribution
    - Separate sampling for metal-to-metal and metal-to-rock friction coefficients

Vibratory Ground Motion Inputs and Methodology

(Continued)

- **Typical mechanical properties**
  - Uncertainties assumed negligible compared to acceleration time history and friction coefficients
- **Corrosion-resistant Barrier Thickness**
  - Shell thickness is assumed to be 18 mm
  - Represents a 2 mm reduction due to general corrosion from emplacement to 10,000 years

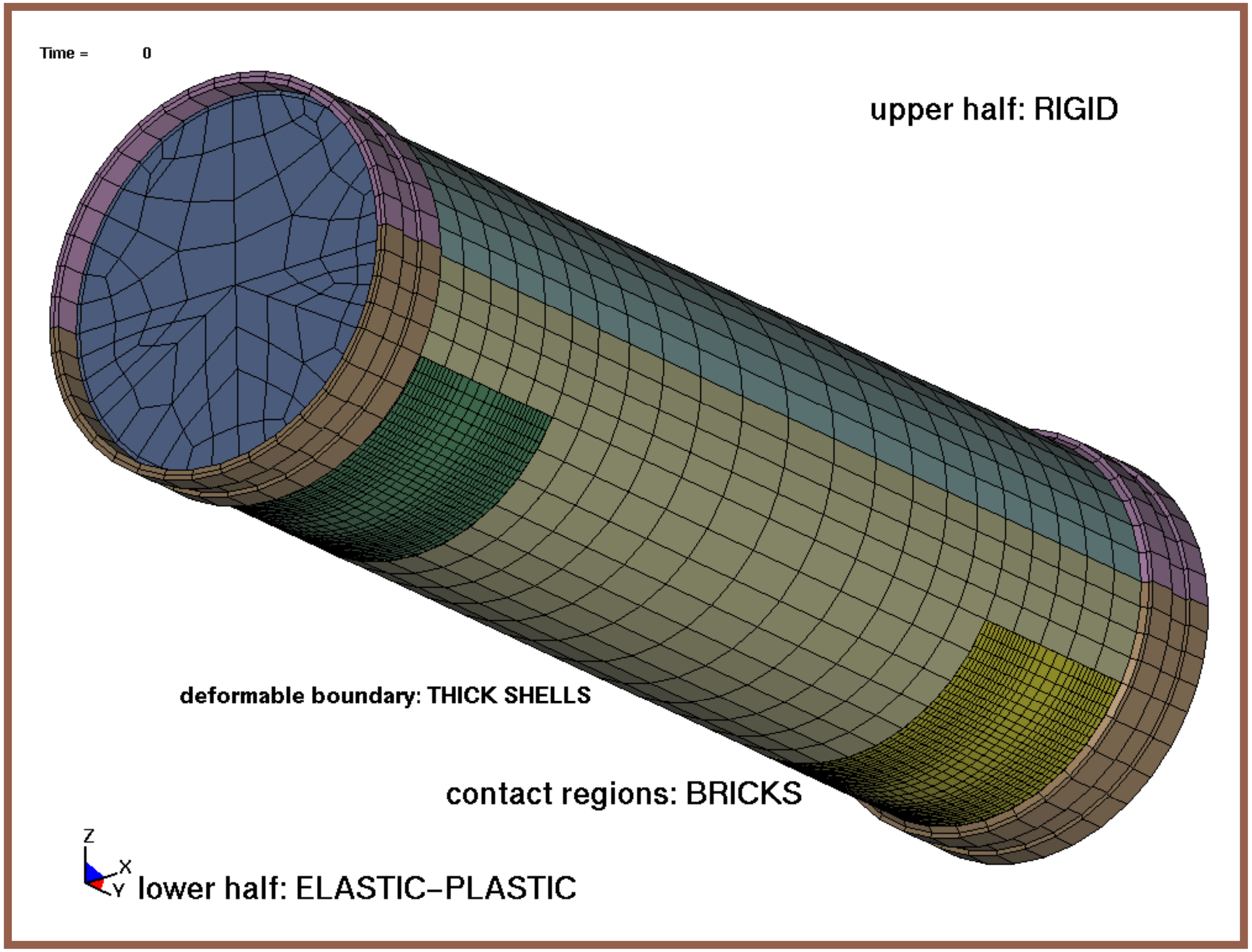
Vibratory Ground Motion Inputs and Methodology
(Continued)

- Temperature is assumed to be 150°C for temperature-dependent properties
- No system damping
  – Regulatory fractions are allowed for elastic analyses
  – Analyses of unanchored structures require a defensible definition of critical damping

Problem Domain Division

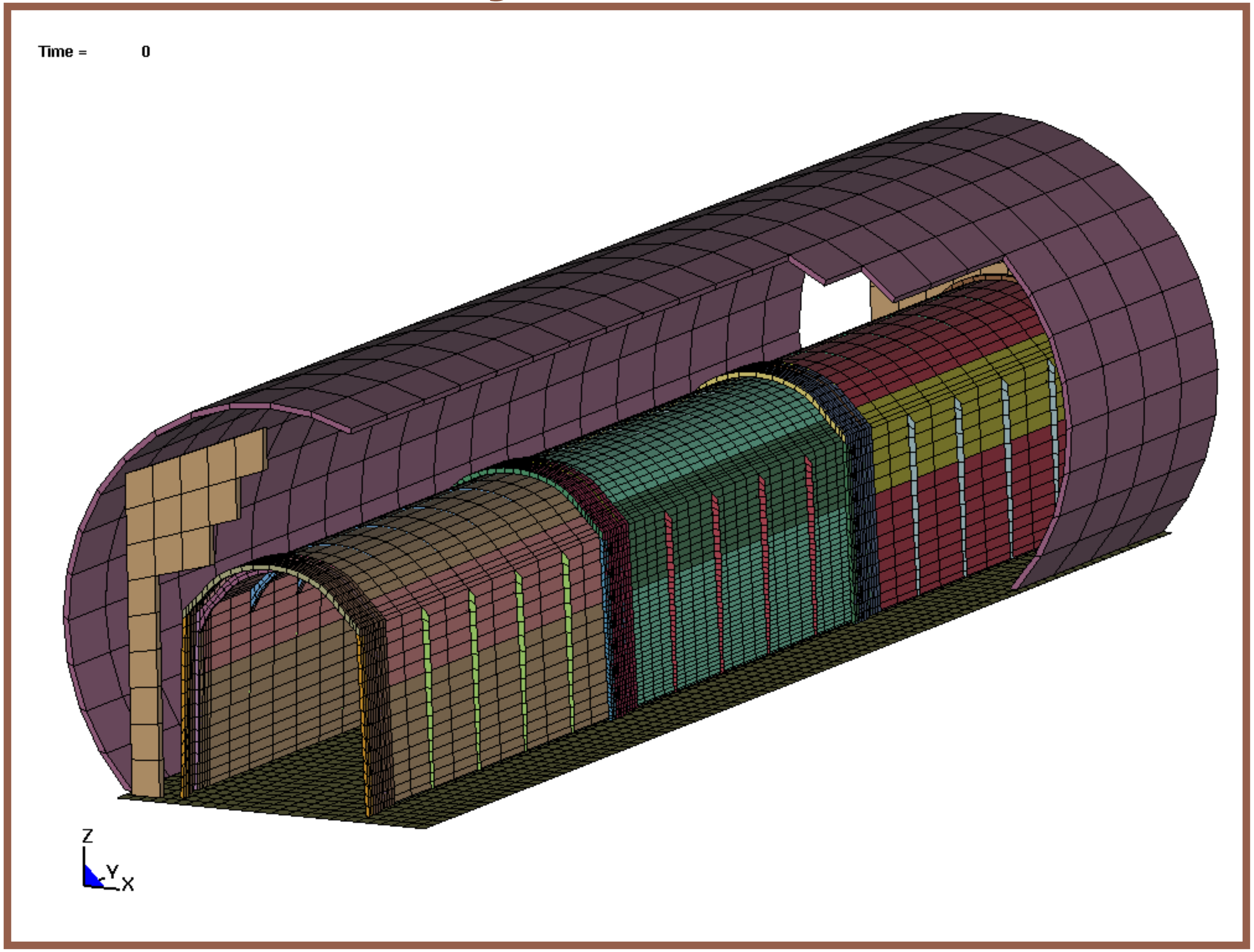
- **Structural response differs based on magnitude of ground motion and component interactions**
  - **lower ground accelerations (≤ 3 g peak ground acceleration (PGA))**
    - **waste package-emplacement pallet interaction is “hammer and anvil” effect**
    - **little effect for drip shield**
  - **higher ground accelerations (> 3 g PGA)**
    - **waste package-emplacement pallet “hammer and anvil” effect is reduced due to increased rigid-body motion**
    - **multiple interactions among waste package, emplacement pallet, drip shield and drift wall assessed in kinematic simulations**
    - **interactions represented as localized impacts**

Finite Element Representation of Waste Package



Preliminary

Finite Element Analysis Representation of Drip Shields for Vibratory Ground Motion Evaluations



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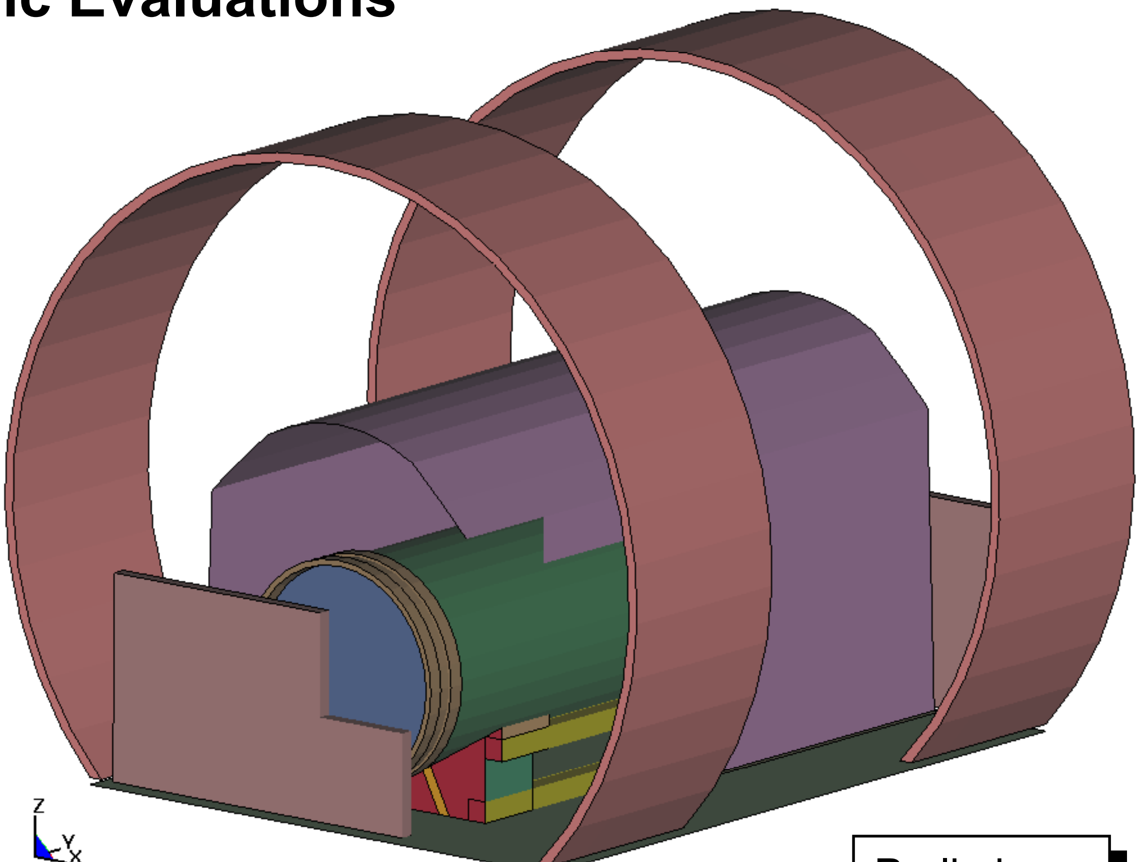
Finite Element Analysis Representation of Drift Segment for Vibratory Ground Motion Evaluations

Finite Element Analysis Representation of Drift Segment for Seismic Evaluations



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Vibratory Ground Motion Results (10^{-6})

Realization Number	Ground Motion Number	Area above Stress Threshold					
		WP-Pallet Interaction (m^2)		WP-WP Interaction (m^2)		Cumulative (m^2; % of total OS area)	
		80% Yield Strength	90% Yield Strength	80% Yield Strength	90% Yield Strength	80% Yield Strength	90% Yield Strength
1	7	0.0029; 0.010%	0.0014; 0.0050%	0.024; 0.085%	0.012; 0.043%	0.027; 0.096%	0.013; 0.046%
2	16	0; 0	0; 0	0.017; 0.060%	0.0089; 0.032%	0.017; 0.060%	0.0089; 0.032%
3	4	0.0050; 0.018%	0; 0	0.19; 0.67%	0.083; 0.29%	0.20; 0.71%	0.083; 0.29%
4	8	0.030; 0.11%	0.0064; 0.023%	0.12; 0.43%	0.061; 0.22%	0.15; 0.53%	0.067; 0.24%
5	11	0.0015; 0.0053	0; 0	0.15; 0.53%	0.070; 0.25%	0.15; 0.53%	0.070; 0.25%
6	1	0.025; 0.089%	0.0028; 0.0099%	0.15; 0.53%	0.063; 0.22%	0.18; 0.64%	0.066; 0.23%
7	2	0.017; 0.060%	0; 0	0.11; 0.39%	0.057; 0.20%	0.13; 0.46%	0.057; 0.20%
8	13	0; 0	0; 0	0.023; 0.082%	0.012; 0.043%	0.023; 0.082%	0.012; 0.043%
9	10	0.0035; 0.012%	0; 0	0.11; 0.39%	0.057; 0.20%	0.11; 0.39%	0.057; 0.20%
10	9	0; 0	0; 0	0.014; 0.050%	0.0071; 0.025%	0.014; 0.050%	0.0071; 0.025%
11	5	0.012; 0.043%	0.0037; 0.013%	0.074; 0.26%	0.032; 0.11%	0.086; 0.30%	0.036; 0.13%
12	6	0.0039; 0.014%	0; 0	0.062; 0.22%	0.031; 0.11%	0.066; 0.23%	0.031; 0.11%
13	12	0; 0	0; 0	0.032; 0.11%	0.016; 0.057%	0.032; 0.11%	0.016; 0.057%
14	14	0.010; 0.035%	0.0043; 0.015%	0.0066; 0.023%	0.0029; 0.010%	0.017; 0.060%	0.0072; 0.026%
15	3	0.0078; 0.028%	0.0015; 0.0053%	0.020; 0.071%	0.010; 0.035%	0.028; 0.099%	0.012; 0.043%

OS = Outer Shell
WP =Waste Package

Preliminary and Unchecked Results

Vibratory Ground Motion Results (10^{-7})

Realization Number	Ground Motion Number	Area above Stress Threshold					
		WP-Pallet Interaction (m^2)		WP-WP Interaction (m^2)		Cumulative (m^2; % of total OS area)	
		80% Yield Strength	90% Yield Strength	80% Yield Strength	90% Yield Strength	80% Yield Strength	90% Yield Strength
1	7	0.20; 0.71%	0.17; 0.60%	0.16; 0.57%	0.086; 0.30%	0.36; 1.28%	0.26; 0.92%
2	16	TBD	TBD	0.048; 0.17%	0.025; 0.089%	TBD	TBD
3	4	0.096; 0.34%	0.083; 0.29%	0.42; 1.49%	0.17; 0.60%	0.52; 1.84%	0.25; 0.89%
4	8	0.12; 0.43%	0.096; 0.34%	0.11; 0.39%	0.050; 0.18%	0.23; 0.78%	0.15; 0.53%
5	11	0.093; 0.33%	0.071; 0.25%	0.18; 0.64%	0.080; 0.28%	0.27; 0.96%	0.15; 0.53%
6	1	0.046; 0.16%	0.024; 0.085%	0.42; 1.49%	0.15; 0.53%	0.47; 1.67%	0.17; 0.60%
7	2	0.038; 0.13%	0.028; 0.099%	0.35; 1.24%	0.15; 0.53%	0.39; 1.38%	0.18; 0.64%
8	13	0.095; 0.34%	0.068; 0.24%	0.30; 1.06%	0.14; 0.50%	0.40; 1.42%	0.21; 0.74%
9	10	0.0052; 0.018%	0.0035; 0.012%	0.034; 0.12%	0.017; 0.060%	0.039; 0.14%	0.021; 0.074%
10	9	0.16; 0.57%	0.14; 0.50%	0.27; 0.96%	0.12; 0.43%	0.43; 1.52%	0.26; 0.92%
11	5	0.0016; 0.0057%	0; 0	0.25; 0.89%	0.11; 0.39%	0.25; 0.89%	0.11; 0.39%
12	6	0.062; 0.22%	0.041; 0.15%	0.10; 0.35%	0.044; 0.16%	0.16; 0.57%	0.085; 0.30%
13	12	0.027; 0.096%	0.018; 0.064%	0.16; 0.57%	0.073; 0.026%	0.19; 0.67%	0.091; 0.32%
14	14	0.020; 0.071%	0.016; 0.057%	0.0077; 0.027%	0.0040; 0.014%	0.028; 0.099%	0.020; 0.071%
15	3	0.045; 0.16%	0.031; 0.11%	0.43; 1.52%	0.21; 0.74%	0.48%; 1.70%	0.24; 0.85%

OS = Outer Shell
WP =Waste Package

Preliminary and Unchecked Results

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Rock Fall Impact Assumptions

- The rock shape is assumed to be a rectangular prism
  - Rock center-of-gravity is located directly above the point of impact
  - Transfers the maximum linear momentum to the drift shield
  - The sharp edge of the prism results in maximum strain on the DS plate
- Drip shield walls free to move in lateral direction
  - Friction coefficient is specified between the drip shield and invert

Rock Fall Impact Assumptions
(Continued)

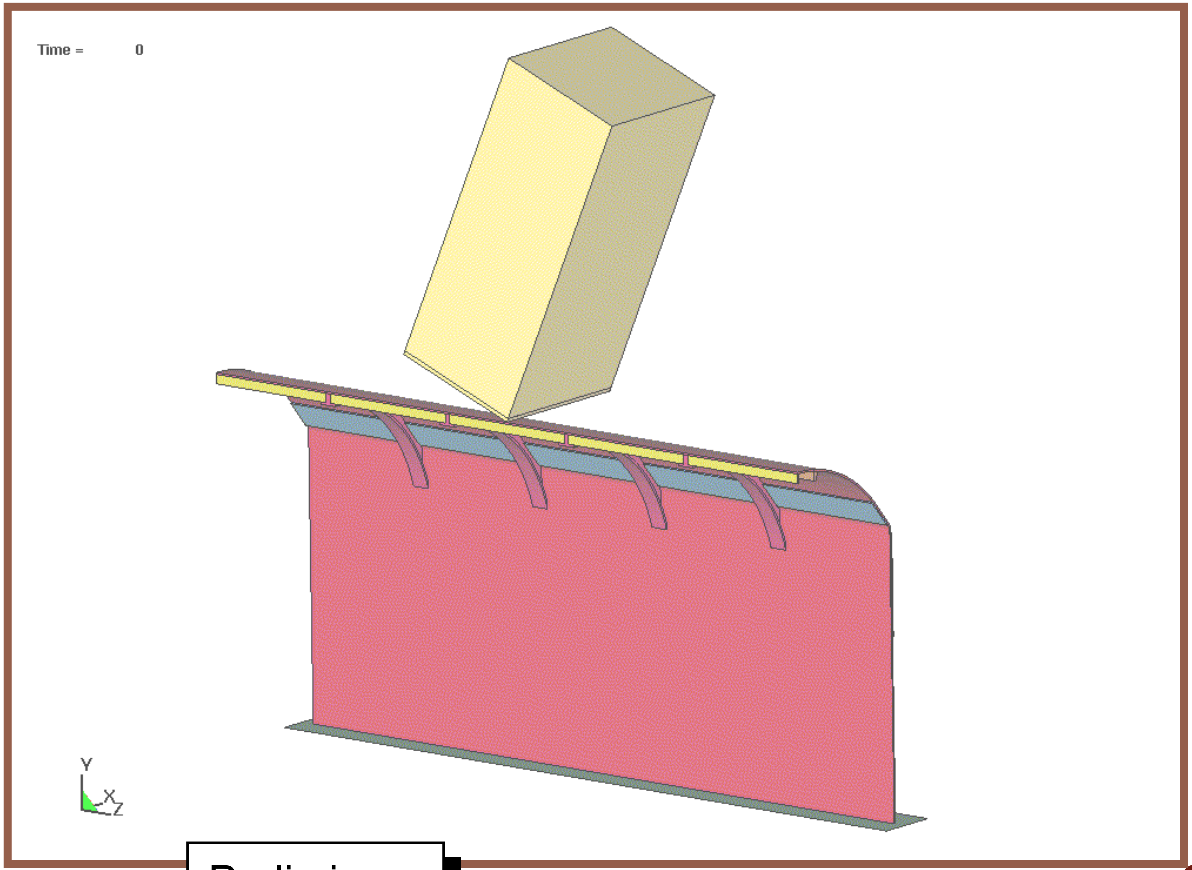
- 150°C used to determine material properties
- Maximum rock unconfined compressive strength used in an elastic-plastic rock stress-strain curve
  – A slightly conservative assumption since the significance of variation in rock strength is negligibly small compared to variation in rock kinetic energy
- Titanium Thickness
  – Ti-7 and Ti-24 reduced by 2 mm
  – Represents reduction due to general corrosion from emplacement to 10,000 years

Rock Fall Impact Inputs and Methodology

- **Rock Characteristics**
  - Obtained from 3DEC simulations as described in previous presentation
- **Drip Shield Representation**
  - 3-D finite element analysis representation developed to evaluate the drip shield structural response to rock fall
  - Parametric calculations performed to prepare a catalog of 15 results
    - five values for kinetic energy (i. e., mass and velocity)
    - three impact locations (vertical, corner, and side-wall)
  - Maximum rock kinetic energy of 10^{-7} ground motion exceeds that of 10^{-6} ground motion
    - Additional set of results added to catalog
  - The results are provided in terms of areas that exceed 50% of the titanium yield strength

Finite Element Analysis Representation of Rock Fall Impact

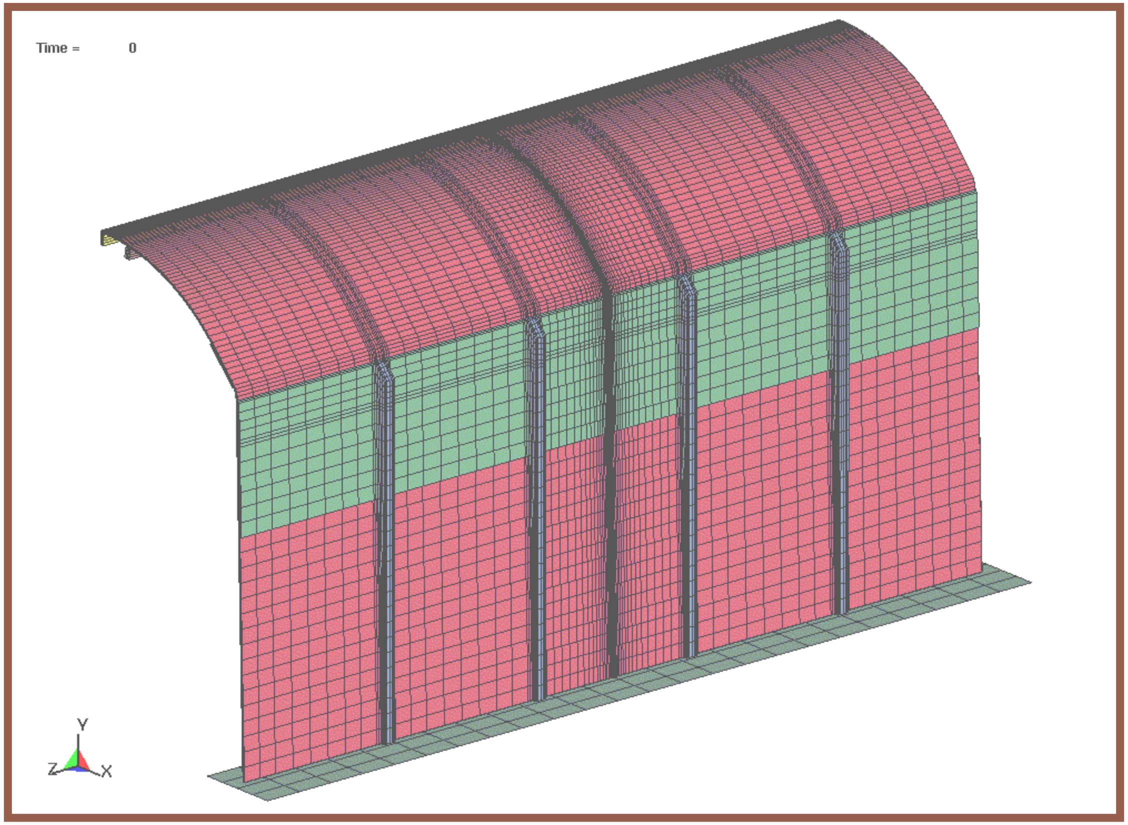
Finite element analysis geometry (half-symmetry) for rock fall impact on drip shield (14.5 t rock shown)



Preliminary

Finite Element Representation for Rock Fall Impact

Finite Element Representation of Drip Shield



Preliminary

Rock Fall Impact Results

Results to Date (10^{-6} Ground Motion)

LS-DYNA Finite Element Analysis Results for Seismic Rock Fall on Drip Shield (DS)

Rock Mass and Kinetic Energy	Area Exceeding Stress Limit (m^2)		
	Vertical Rock Fall (90° from horizontal)	Rock Fall onto DS Corner (60° from horizontal)	Rock Fall onto DS Side-wall (40° from horizontal)
14.5 MT Rock (163083 J)	3.5080	0.6071	0.0790
3.3 MT Rock (24712 J)	0.5440	0.4158	0.0
0.15 MT Rock (902 J)	0.0015	0.0091	0.0
0.11 MT Rock (42 J)	0.0	0.0	0.0
0.25 MT Rock (0.005 J)	0.0	0.0	0.0

MT: metric tons (1 MT = 1000 kg)
J:Joule

Preliminary and Unchecked Results

Rock Fall Impact Results
(Continued)

Results to Date (10^{-7} Ground Motion)

LS-DYNA Finite Element Analysis Results for Seismic Rock Fall on Drip Shield (DS)
(This table is used in conjunction with 10^{-6} results
for assessment of rock fall damage to DS)

Rock Mass and Kinetic Energy	Area Exceeding Stress Threshold (m^2)		
	Vertical Rock Fall (90° from horizontal)	Rock Fall onto DS Corner (60° from horizontal)	Rock Fall onto DS Side-wall (40° from horizontal)
11.5 MT Rock (348174 J)	4.2984	4.5054	1.1263

MT: metric tons (1 MT = 1000 kg)
J:Joule

Preliminary and Unchecked Results

Summary

- Presented analytical approach for addressing vibratory ground motion effects and seismically induced rock fall impacts in the post-closure period
  - Ground motion and rock fall de-coupled in analysis
  - Impacts treated in accordance with predominate features and corresponding damage accrued
- Presented results to date
- Approach is appropriate for full range of ground motions