CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

CNWRA
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Doug Gute 210.522.2307
George Adams 210-522-4957 (Primary Holder)

Repository Design and Thermal-Mechanical Effects

This notebook documents the work being done to develop conceptual models including process-level drip shield and waste package analyses and rockfall study for upgrading the SEISMO module to be included in the future version of the Total-system Performance Assessment (TPA) code. See the Operations Plan for Repository Design and Thermal-Mechanical Effects (RDTME) for more details.

The qualifications required of the staff supporting this endeavor are as follows:

a) Computational Continuum Mechanics / Finite Element Analysis
b) Material Science / Metallurgy
c) Rock Mechanics
d) Civil and Mechanical Engineering
e) Geological Science and Engineering

CNWRA Staff:

Doug Gute [signature]
Simon Hsiung [signature]
Darrell Dunn [signature]
Asad Chowdhury [signature]

Outside Consulting Staff:

Ted Krauthammer
added 2/21/02 George Adams [signature]

George Adams is the primary holder of this scientific notebook. [signature] 1-26-2007

[signature] 6/30/2000

2/27/02 [signature]

SAI Add Rockfall Effects on Drip Shield to SEISMO

Participants:

George Adams [signature]

The objectives of this task are in accordance with SCR Number: PA-SCR-385 and section 2.9 of the Software Requirements Description for the Total-System Performance Assessment Version 5.0 Code. The objectives are described as follows: Currently the SEISMO module of the TPA code calculates rockfall effects on the waste package only. With the anticipated modification to include a model of the drip shield failure, the SEISMO module will need to be updated to include the effects of rockfall on the drip shield. The SEISMO module will provide the number of drip shield failures and waste package failures for each seismic event.

The approach to achieving the objectives will be in accordance with the Software Development Plan for the Total-System Performance Assessment Version 5.0 Code.

SAI is referenced in section 3.1.27

Qualifications:

Proficiency in developing, implementing and testing FORTRAN 77 code.

2/28/02 [signature]

FOR this coding effort, TPA code was checked-out in accordance with configuration procedures identified in the Software Development Plan for the Total-System Performance Assessment Version 5.0 Code.

During software development, the TPA code was placed on the following machine: GRADAMS2.datasys.swri.edu. This is a Microsoft Windows 2000 laptop. The source code directory is: c:\CNWRA\tpa. The software development directory is: c:\CNWRA\Project_20-1402-762\PA-SCR-385. Software will be developed on this machine using the Lahey-Fujitsu FORTRAN 95 v5.6 development environment.

3/11/02 [signature] The repository is divided into a number of grid elements and computations are performed on these grid elements. The number of grid elements used may affect the computational results. Therefore, the number of grid elements is a parameter that can be modified easily for different analyses.

[signature]
7/18/02

3/11/02 George Adams In - Process Entries

3/11/02 George Adams

The SEISMO module was rewritten to incorporate the effects of rockfall on the drip shield. High-level modules have been implemented; however, low-level modules have not. Low-level modules will be documented as they are added.

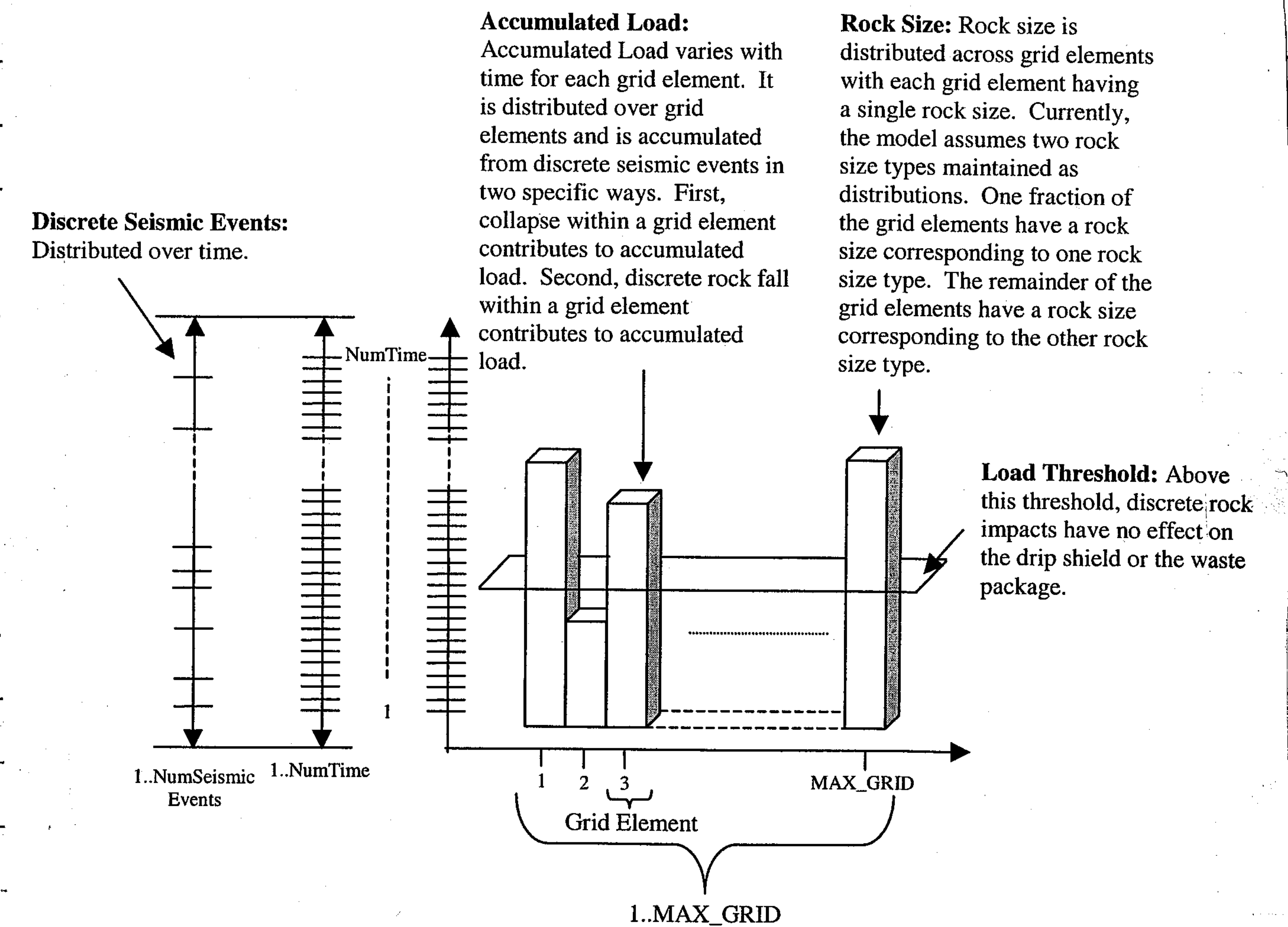
George R Adams 7/18/02

7/18/02 George Adams

The baseline design model is included on this page. Changes will be made to this model as discussions proceed.

George Adams 7/18/02

Design Model

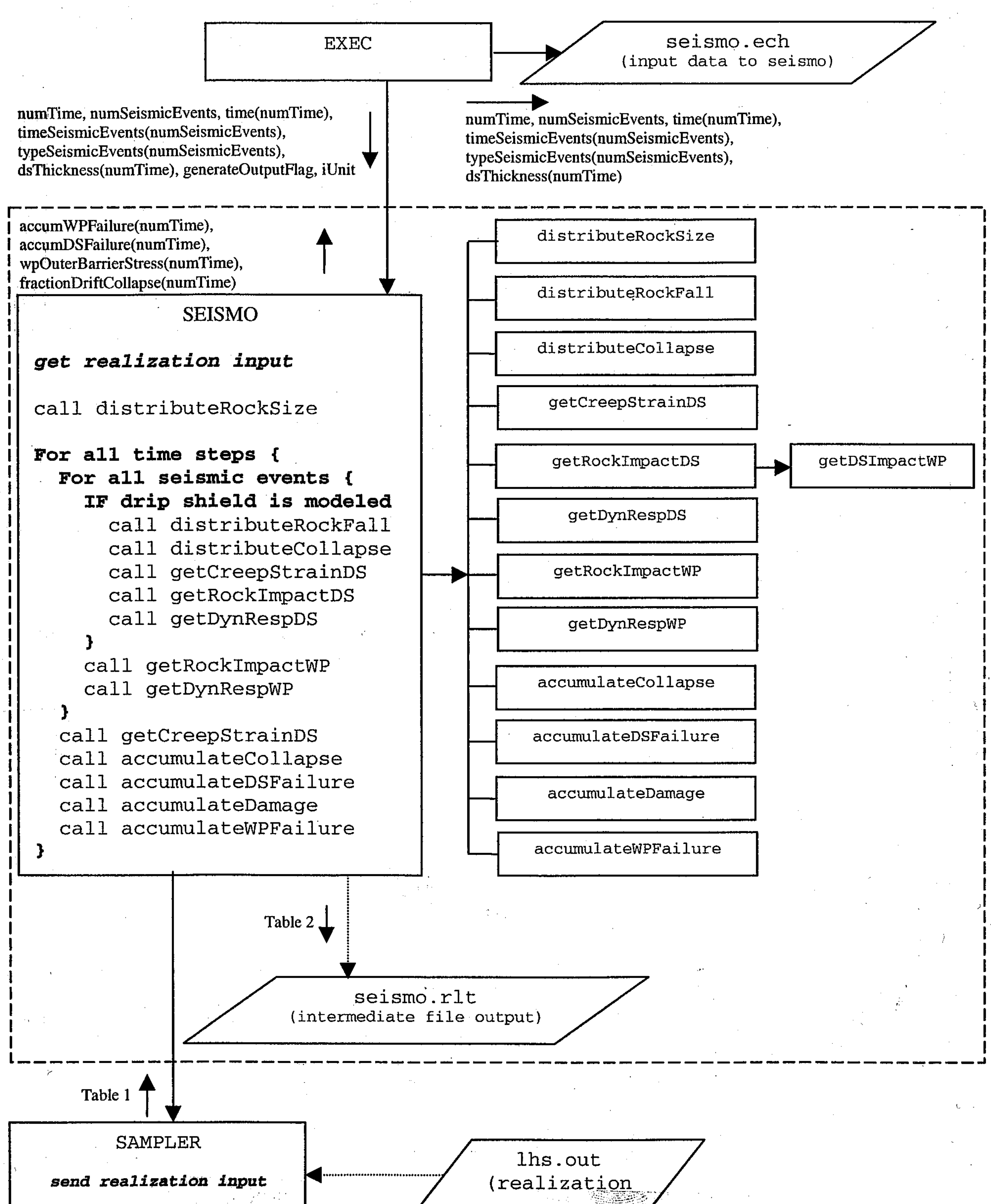


Assumptions:

1) The repository can be divided into discrete grid elements.
2) Uniformity exists within a grid element. Each grid element has a single rock size. Load is accumulated within each grid element from a discrete rock fall within that grid element and from any collapse within that grid element.
3) Waste packages are distributed uniformly throughout the repository so that each grid element represents a uniform fraction of waste packages (and their associated drip shields).
4) Waste package stress, and drip shield strain, stress, and displacement within a grid element applies to all waste packages and drip shields within that grid element.
5) Failure within a grid element (waste package and/or drip shield) applies to all of the waste packages and/or drip shields within that grid element.
6) On entry into SEISMO, no waste package or drip shield has failed as a result of any other failure mechanism.

George Adams 7/18/02

Flowchart



7/18/02 George Adams

The baseline flowchart corresponding to the baseline design model is shown on page 6. The baseline model includes rock size distributions, rockfall distributions, and collapse load distributions across a configurable number of grid elements. The module, SEISMO, is composed of a series of subroutines that are invoked across time steps and seismic events. This module's interface to the executive, EXEC, is shown below.

George Adams 7/18/02

Subroutine Seismo

Interface for Subroutine SEISMO

	Main SEISMO subroutine
Constant:	MAXGRID = 100, MAXROCK = 2, MAXCOMP = 3
Input:	numTime, time(1..numTime), numSeismicEvents, timeSeismicEvents(1..numSeismicEvents), typeSeismicEvents(1..numSeismicEvents), dsThickness(1..numTime), generateOutputFlag, iUnit
Realization Input:	RockSizeType(1..maxrock), ThresholdLoad, DSWPInitialClearance, DSMinimumThickness, DSCreepStrainThreshold, DripShieldFlag, BackFillFlag, MaxStressFlag
Output:	accumWPFailure(1..numTime), accumDSFailure(1..numTime), fractionDriftCollapse(1..numTime), wpOuterBarrierStress(1..numTime)
Intermediate File Output:	time(1..numTime), accumWPFailure(1..numTime), accumDSFailure(1..numTime), wpOuterBarrierStress(1..numTime), fractionDriftCollapse(1..numTime),
	==Unit Test Output==
	realization inputs
	residual_disp_ds(1..MAXGRID), residual_stress_ds(1..MAXCOMP, 1..MAXGRID), peeq_ds(1..MAXCOMP, 1..MAXGRID), c_strain_ds(1..MAXCOMP, 1..MAXGRID), residual_stress_pallet(1..MAXGRID), peeq_pallet(1..MAXGRID), residual_stress_inner(1..MAXGRID), peeq_inner(1..MAXGRID), residual_stress_outer(1..MAXGRID), peeq_outer(1..MAXGRID), rock_size(1..MAXGRID), rock_load(1..MAXGRID), collapse_load(1..MAXGRID), accum_load(1..MAXGRID), typeSeismicEvents(1..numSeismicEvents), timeSeismicEvents(1..numSeismicEvents)

7/18/02 George Adams

The following changes have been identified for the baseline design model:

1) A data input file will be required that includes a rock mass quality and bulking factor for each grid element. The rock mass quality will be used in the calculation of a minimum peak ground acceleration required for discrete rock fall.
2) Discrete rock fall will not be added into accumulated load within a grid element. Load within a grid element will only be accumulated from collapse within the grid element.
3) Rock fall height will be a function of the accumulated collapse load and will not have a dependency on previous rock falls.
4) Load will be accumulated from collapse within a grid element up to a drift collapse threshold. Above this drift collapse threshold there is no more room within the grid element for additional collapse.
5) The accumulated load due to collapse will be generated over discrete time steps whether or not a seismic event occurred during that time step.

George Adams 7-26-02

7/26/02 George Adams

Table 1 is referenced on the baseline flowchart on page 6. This table identifies the realization input parameters for SEISMO. Both the currently used and those planned to be used are included in the table.

George Adams 7-26-02

Table 1. TPA.INP

Parameter	Definition	Type	Current	Future
BackFillFlag	Consider backfill in the analysis.	flag	no	yes
DistributionJointSpacing(1..5)forSEISMO	Fractional areal coverage for rock condition (1..5)	constant	yes	
DSCreepStrainThreshold	Creep Strain threshold above which deformation of the drip shield will take place.	constant	no	yes
DripShieldFlag	Consider the drip shield in the analysis.	flag	no	yes
DSMinimumThickness	Minimum thickness of the drip shield. Below this value, the drip shield is considered failed.	constant	no	yes
DSWPInitialClearance	Initial clearance between the waste package and the drip shield	constant	no	yes
FractionalAreaForGroundMotion(1..10)	Fractional rockfall area for ground motion type (1..10)	constant	yes	
GrainDensityforTSw2SEISMO[]	Grain density for Topopah Spring—welded (g/cm^3)	constant	yes	
InnerWPThickness[m]	(Not identified with seismo)	constant	yes	
ThresholdLoad	Load threshold above which rock impacts have no effect.	constant	no	yes
MaxStressFlag	Return the maximum stress instead of the average stress for waste package outer barrier stress.	flag	no	yes
OuterWPThickness[m]	(Not identified with seismo)	constant	yes	
RockFallingDistanceforSEISMO[m]	Rock falling distance gap between the top of WP and the drift crown (m)	constant	yes	
RockModulusOfElasticityforSEISMO[Pa]	Rock modulus of elasticity (Pa)	normal	yes	
RockPoissonRatioforSEISMO[]	Rock Poisson ratio	normal	yes	
RockSizeType1[kg/m]	Rock size corresponding to a particular rock type in the repository. (kg/m)	distribution	no	yes
RockSizeType2[kg/m]	Rock size corresponding to a particular rock type in the repository. (kg/m)	distribution	no	yes
SeedForRandomNumberForSEISMO	A random number seed for sampling the time and magnitude of seismic events	constant	included in reader	yes
SeismicHazardCurveforSEISMO	Minimum peak ground acceleration for bins, return period (yr); number of magnitudes for recurrence of seismic events, magnitude, and recurrence time	hazardcurve	included in exec	yes
SEISMOJointSpacing(1..5)[m]	Joint spacing (JS) for rock condition (1..5)	normal	yes	
VerticalExtendOfRockFall(1..5)_(1..10)	Vertical extent of rock fall for rock condition (1..5) and ground acceleration (1..10): Parameters for ground acceleration: 0.05g, 0.10g, 0.15g, 0.20g, 0.25g, 0.30g, 0.35g, 0.40g, 0.45g, 0.50g	constant/uniform	yes	
WeightOfWPforSEISMO[N]	Weight of WP used in impact calculation during free fall (N)	constant	yes	
WeightPercentageOfRockFallThatHitsWPforSEISMO	Weight percentage of rock fall that hits WP	constant	yes	
WPFallingDistanceforSEISMO[m]	WP falling distance for freefall calculations (m)	constant	yes	
WPModulusOfElasticityforSEISMO[Pa]	WP modulus of elasticity (Pa)	constant	yes	
WPNumberofSupportPairforSEISMO	Number of support pairs on the WP pedestal	iconstant	yes	
WPPlasticElongation[]	WP plastic elongation	constant	yes	
WPPoissonRatioforSEISMO[]	WP Poisson ratio	constant	yes	
WPSupportStiffnessforSEISMO[pa*m]	Stiffness of the pedestal	constant	yes	
WPUltimateStrength[N/m^2]	Ultimate strength of WP (N/m^2)	constant	yes	
WPYieldPoint[]	WP yield point	constant	yes	
YieldStrength[Mpa]	Yield strength of outer overpack, Mpa	constant	yes	

7/26/02 George Adams

Table 2 is referenced on the baseline flowchart on page 6. This table identifies the intermediate file output parameters for the baseline model.

George Adams 7-26-02

Table 2. SEISMO.RLT

Parameter	Unit Test	Definition
accum_load(1..MAXGRID)	yes	Accumulated load over all grid elements.
accumDSFailure(1..numTime)	no	Accumulated drip shield failure over the analysis period.
accumWPFailure(1..numTime)	no	Accumulated waste package failure over the the analysis period
c_strain_ds(1..MAXDSCOMP, 1..MAXGRID)	yes	Maximum creep strain for each component in the drip shield over all grid elements.
collapse_load	yes	Collapse load distribution over all grid elements.
fractionDriftCollapse(1..numTime)	no	Fraction of drift collapse over the analysis period.
peeq_ds(1..MAXCOMP, 1..MAXGRID)	yes	Equivalent plastic strain in the drip shield for each component over all grid elements.
peeq_inner(1..MAXGRID)	yes	Equivalent plastic strain on the waste package inner barrier.
peeq_outer(1..MAXGRID)	yes	Equivalent plastic strain on the waste package outer barrier.
peeq_pallet(1..MAXGRID)	yes	Equivalent plastic strain on the pallet.
residual_disp_ds(1..MAXGRID)	yes	Maximum displacement of the drip shield over all grid elements.
residual_stress_ds(1..MAXCOMP, 1..MAXGRID)	yes	Maximum mises stress for each component in the drip shield over all grid elements.
residual_stress_inner(1..MAXGRID)	yes	Maximum mises stress in the inner barrier of the waste package over all grid elements.
residual_stress_outer(1..MAXGRID)	yes	Maximum mises stress in the outer barrier of the waste package over all grid elements.
residual_stress_pallet(1..MAXGRID)	yes	Maximum mises stress in the pallet over all grid elements.
rock_load(1..MAXGRID)	yes	Rock fall distribution over all grid elements.
rock_size(1..MAXGRID)	yes	Rock size distribution over all grid elements.
time(1..numTime)	no	Time intervals for analysis
timeSeismicEvents(1..numSeismicEvents)	yes	Time of the seismic event.
typeSeismicEvents(1..numSeismicEvents)	yes	Seismic load
wpOuterBarrierStress(1..numTime)	no	Waste package outer barrier stress over the analysis period.

7/26/02 George Adams

The update to the baseline design model is shown on page 11. The primary design changes include the addition of rock mass quality and bulking factor, the inclusion of a drift collapse height threshold, and the definition of accumulated load to include drift collapse and not discrete rock fall.

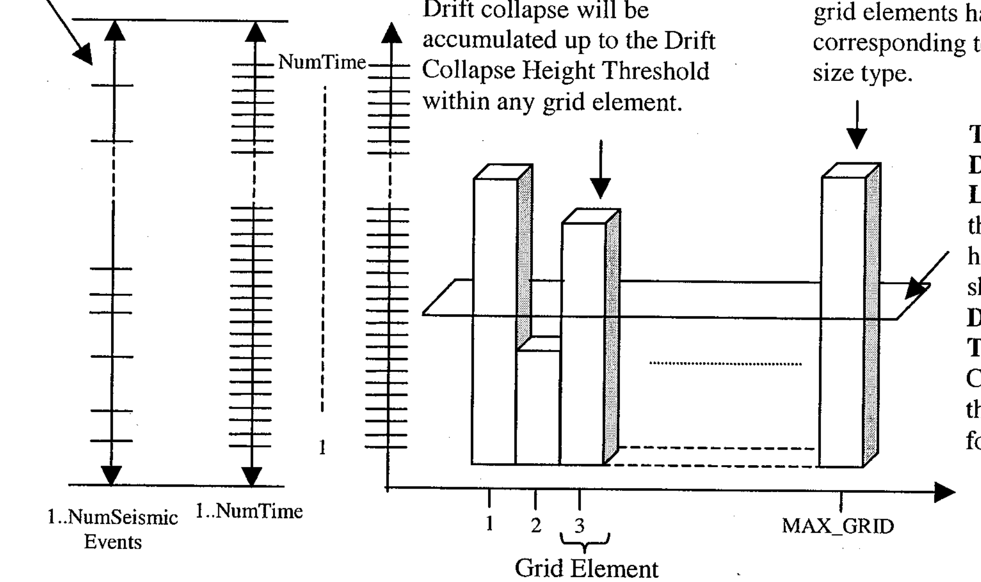
George Adams 7-26-02

Design Model

Discrete Seismic Events: Distributed over time.

Accumulated Load: Accumulated Load varies with time for each grid element. It is distributed over grid elements and is accumulated from drift collapse within a grid element. Drift collapse will occur at discrete time steps whether or not a seismic event occurred within that time step. Drift collapse will be accumulated up to the Drift Collapse Height Threshold within any grid element.

Rock Size: Rock size is distributed across grid elements with each grid element having a single rock size. Currently, the model assumes two rock size types maintained as distributions. One fraction of the grid elements have a rock size corresponding to one rock size type. The remainder of the grid elements have a rock size corresponding to the other rock size type.



Thresholds:
Discrete Rock Impact Load Threshold: Above this load, discrete rock falls have no effect on the drip shield or the waste package.
Drift Collapse Height Threshold: Above the Drift Collapse Height threshold, there is no additional room for collapse.

Grid Element Parameters:

Rock Size: Rock size is distributed across grid elements with each grid element having a single rock size. Currently, the model assumes two rock size types maintained as distributions. One fraction of the grid elements have a rock size corresponding to one rock size type. The remainder of the grid elements have a rock size corresponding to the other rock size type.

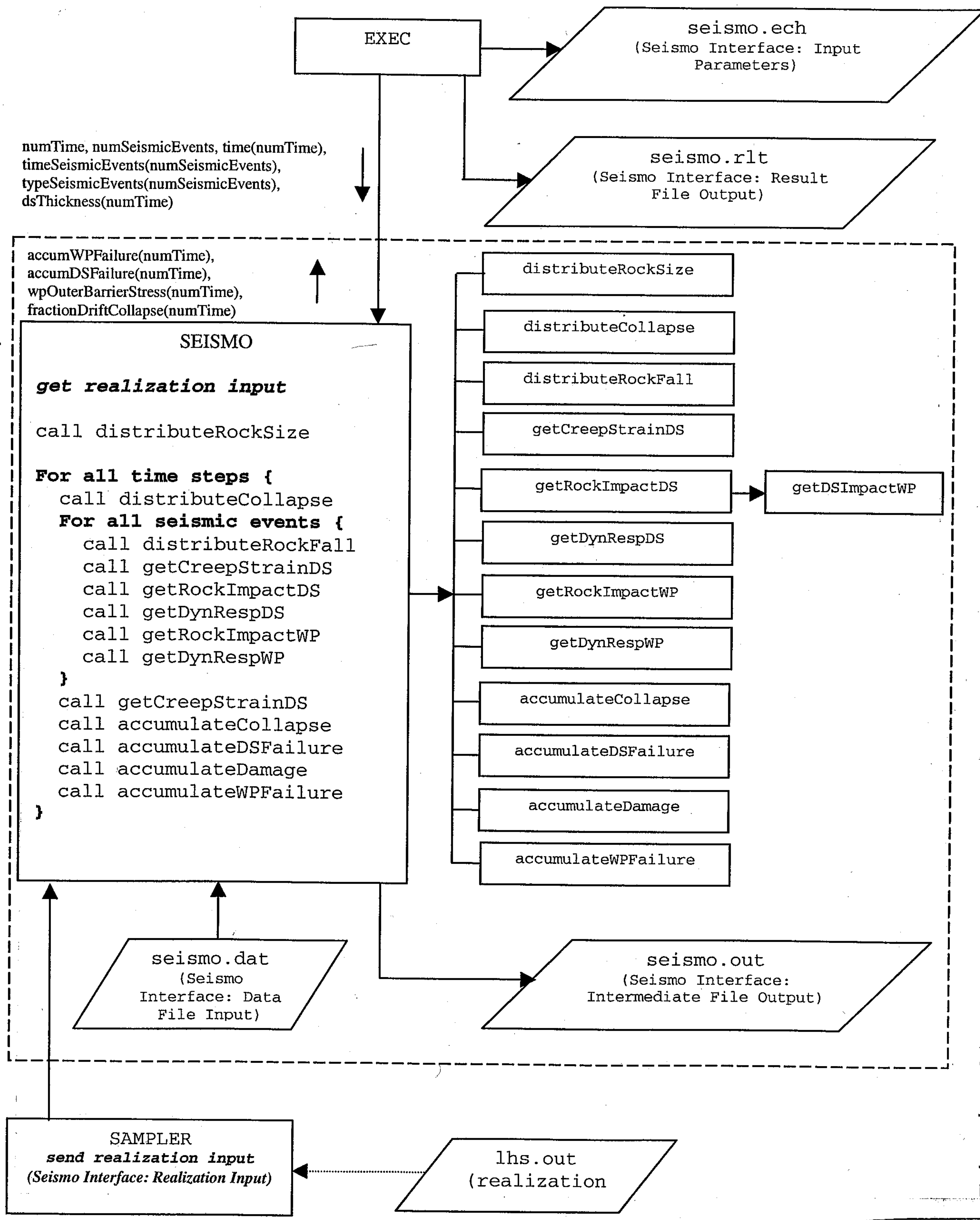
Rock Mass Quality: Each grid element is assigned a rock mass quality. The rock mass quality is used in the calculation of a minimum peak ground acceleration required for discrete rock fall.

Bulking Factor: Each grid element is assigned a bulking factor. The bulking factor is used in both the calculation of the drift collapse height threshold and the height resulting from a drift collapse within any grid element.

Assumptions:
1) The repository can be divided into discrete grid elements.
2) Load is accumulated within each grid element from any drift collapse within that grid element. Subsequent rock fall height is a function of accumulated collapse load within the grid element.
3) Waste packages are distributed uniformly throughout the repository so that each grid element represents a uniform fraction of waste packages (and their associated drip shields).
4) Waste package stress, and drip shield strain, stress, and displacement within a grid element applies to all waste packages and drip shields within that grid element.
5) Failure within a grid element (waste package and/or drip shield) applies to all of the waste packages and/or drip shields within that grid element.
6) On entry into SEISMO, no waste package or drip shield has failed as a result of any other failure mechanism.

George Adams 7-26-02

Flowchart and Data Flow Diagram



7-26-02 George Adams

The updated flowchart and data flow diagram is included on page 12. This update shows the addition of a data file for input (seismo.dat), the use of an output file (seismo.out) for intermediate output, and the movement of the result file (seismo.rlt) outside of the seismo module. In addition, the subroutine, distributeCollapse, is moved outside of the "For all seismic events" loop since drift collapse occurs at discrete time steps regardless of seismic activity. The condition, "If drip shield is modeled" is removed since drip shield thickness (dsThickness) is received and a zero thickness would be the equivalent of this condition. This change was done for uniformity with other TPA code modules.

George Adams 7-26-02

7-26-02 George Adams

The updated SEISMO interface is shown on this page. This update shows the addition of a data file input section for bulking factor and rock mass quality, and the separation of file output into a result file output (seismo.rlt) and intermediate file output (seismo.out).

George Adams 7-26-02

Seismo Interface

Interface for Subroutine SEISMO	Main SEISMO subroutine
Constant:	MAXGRID = 100, MAXROCK = 2, MAXCOMP = 3
Input Parameters:	numTime, time(1..numTime), numSeismicEvents, timeSeismicEvents(1..numSeismicEvents), typeSeismicEvents(1..numSeismicEvents), dsThickness(1..numTime)
Data File Input:	bulking_factor(1..MAXGRID), rock_mass_quality(1..MAXGRID)
Realization Input:	RockSizeType(1..maxrock), ThresholdLoad, DSWPInitialClearance, DSMinimumThickness, DSCreepStrainThreshold, MaxStressFlag
Output:	accumWPFailure(1..numTime), accumDSFailure(1..numTime), fractionDriftCollapse(1..numTime), wpOuterBarrierStress(1..numTime)
Result File Output:	time(1..numTime), accumWPFailure(1..numTime), accumDSFailure(1..numTime), wpOuterBarrierStress(1..numTime), fractionDriftCollapse(1..numTime),
Intermediate File Output:	***==Unit Test Output==*** *realization inputs* residual_disp_ds(1..MAXGRID), residual_stress_ds(1..MAXCOMP, 1..MAXGRID), peeq_ds(1..MAXCOMP, 1..MAXGRID), c_strain_ds(1..MAXCOMP, 1..MAXGRID), residual_stress_pallet(1..MAXGRID), peeq_pallet(1..MAXGRID), residual_stress_inner(1..MAXGRID), peeq_inner(1..MAXGRID), residual_stress_outer(1..MAXGRID), peeq_outer(1..MAXGRID), rock_size(1..MAXGRID), rock_load(1..MAXGRID), collapse_load(1..MAXGRID), accum_load(1..MAXGRID), typeSeismicEvents(1..numSeismicEvents), timeSeismicEvents(1..numSeismicEvents)

7-26-02 George Adams

Table 1 is the updated table of realization input parameters. BackFillFlag and DripShieldFlag were removed. Information currently in the TPA code can be used in place of these flags.

George Adams 7-26-02

Table 1. TPA.INP Realization Input Parameters

Parameter	Definition	Type	Current	Future
DistributionJointSpacing(1..5)forSEISMO	Fractional areal coverage for rock condition (1..5)	constant	yes	
DSCreepStrainThreshold	Creep Strain threshold above which deformation of the drip shield will take place.	constant	no	yes
DSMinimumThickness	Minimum thickness of the drip shield. Below this value, the drip shield is considered failed.	constant	no	yes
DSWPInitialClearance	Initial clearance between the waste package and the drip shield	constant	no	yes
FractionalAreaForGroundMotion(1..10)	Fractional rockfall area for ground motion type (1..10)	constant	yes	
GrainDensityforTSw2SEISMO[]	Grain density for Topopah Spring—welded (g/cm^3)	constant	yes	
InnerWPThickness[m]	(Not identified with seismo)	constant	yes	
ThresholdLoad	Load threshold above which rock impacts have no effect.	constant	no	yes
MaxStressFlag	Return the maximum stress instead of the average stress for waste package outer barrier stress.	flag	no	yes
OuterWPThickness[m]	(Not identified with seismo)	constant	yes	
RockFallingDistanceforSEISMO[m]	Rock falling distance gap between the top of WP and the drift crown (m)	constant	yes	
RockModulusOfElasticityforSEISMO[Pa]	Rock modulus of elasticity (Pa)	normal	yes	
RockPoissonRatioforSEISMO[]	Rock Poisson ratio	normal	yes	
RockSizeType1[kg/m]	Rock size corresponding to a particular rock type in the repository. (kg/m)	distribution	no	yes
RockSizeType2[kg/m]	Rock size corresponding to a particular rock type in the repository. (kg/m)	distribution	no	yes
SeedForRandomNumberForSEISMO	A random number seed for sampling the time and magnitude of seismic events	constant	included in reader	yes
SeismicHazardCurveforSEISMO	Minimum peak ground acceleration for bins, return period (yr); number of magnitudes for recurrence of seismic events, magnitude, and recurrence time	hazardcurve	included in exec	yes
SEISMOJointSpacing(1..5)[m]	Joint spacing (JS) for rock condition (1..5)	normal	yes	
VerticalExtendOfRockFall(1..5)_(1..10)	Vertical extent of rock fall for rock condition (1..5) and ground acceleration (1..10): Parameters for ground acceleration: 0.05g, 0.10g, 0.15g, 0.20g, 0.25g, 0.30g, 0.35g, 0.40g, 0.45g, 0.50g	constant/unif orm	yes	
WeightOfWPforSEISMO[N]	Weight of WP used in impact calculation during free fall (N)	constant	yes	
WeightPercentageOfRockFallThatHitsWP forSEISMO	Weight percentage of rock fall that hits WP	constant	yes	
WPFallingDistanceforSEISMO[m]	WP falling distance for freefall calculations (m)	constant	yes	
WPModulusOfElasticityforSEISMO[Pa]	WP modulus of elasticity (Pa)	constant	yes	
WPNumberofSupportPairforSEISMO	Number of support pairs on the WP pedestal	iconstant	yes	
WPPlasticElongation[]	WP plastic elongation	constant	yes	
WPPoissonRatioforSEISMO[]	WP Poisson ratio	constant	yes	
WPSupportStiffnessforSEISMO[pa*m]	Stiffness of the pedestal	constant	yes	
WPUltimateStrength[N/m^2]	Ultimate strength of WP (N/m^2)	constant	yes	
WPYieldPoint[]	WP yield point	constant	yes	
YieldStrength[Mpa]	Yield strength of outer overpack, Mpa	constant	yes	

7-26-02 George Adams

Tables 2, 3, and 4 include variable definitions corresponding to the SEISMO Interface on page 14. These tables also map the variables to the data files which corresponds to the information shown on the Flowchart and Data Flow Diagram on page 12.

George Adams 7-26-02

Table 2. SEISMO.RLT Variable Definitions

Parameter	Definition
accumDSFailure(1..numTime)	Accumulated drip shield failure over the analysis period.
accumWPFailure(1..numTime)	Accumulated waste package failure over the the analysis period
fractionDriftCollapse(1..numTime)	Fraction of drift collapse over the analysis period.
time(1..numTime)	Time intervals for analysis
wpOuterBarrierStress(1..numTime)	Waste package outer barrier stress over the analysis period.

Table 3. SEISMO.OUT Variable Definitions

Parameter	Definition
accum_load(1..MAXGRID)	Accumulated load over all grid elements.
c_strain_ds(1..MAXDSCOMP, 1..MAXGRID)	Maximum creep strain for each component in the drip shield over all grid elements.
collapse_load	Collapse load distribution over all grid elements.
peeq_ds(1..MAXCOMP, 1..MAXGRID)	Equivalent plastic strain in the drip shield for each component over all grid elements.
peeq_inner(1..MAXGRID)	Equivalent plastic strain on the waste package inner barrier.
peeq_outer(1..MAXGRID)	Equivalent plastic strain on the waste package outer barrier.
peeq_pallet(1..MAXGRID)	Equivalent plastic strain on the pallet.
residual_disp_ds(1..MAXGRID)	Maximum displacement of the drip shield over all grid elements.
residual_stress_ds(1..MAXCOMP, 1..MAXGRID)	Maximum mises stress for each component in the drip shield over all grid elements.
residual_stress_inner(1..MAXGRID)	Maximum mises stress in the inner barrier of the waste package over all grid elements.
residual_stress_outer(1..MAXGRID)	Maximum mises stress in the outer barrier of the waste package over all grid elements.
residual_stress_pallet(1..MAXGRID)	Maximum mises stress in the pallet over all grid elements.
rock_load(1..MAXGRID)	Rock fall distribution over all grid elements.
rock_size(1..MAXGRID)	Rock size distribution over all grid elements.
timeSeismicEvents(1..numSeismicEvents)	Time of the seismic event.
typeSeismicEvents(1..numSeismicEvents)	Seismic load

Table 4. Data File Input Variable Definitions

Parameter	Definition
bulking_factor(1..MAXGRID)	The bulking factor over all grid elements.
rock_mass_quality(1..MAXGRID)	The rock mass quality over all grid elements.

8-1-02 George Adams

For Table 1 on page 15, the parameter DSCreepStrainThreshold was modified to DSCreepStrainThreshold[m/m], DSMinimumThickness was modified to DSMinimumThickness[m], DSWPInitialClearance was modified to DSWPInitialClearance[m], and ThresholdLoad was modified to ThresholdLoad[kg/m]

9-9-02 George Adams

The SEISMO module was rewritten to drive a standalone module named MECHFAIL. SEISMO retrieves the TPA input parameters, generates an input file for MECHFAIL, invokes MECHFAIL, retrieves its results, and returns these results to the TPA Executive.

9-12-02 George Adams

A driver (SEISDRV) was built to invoke the standalone module MECHFAIL. Output from this driver is placed in file seisdrv.dat and summary data is placed in file mechsum.dat. A test was performed to verify that the average and standard deviation in mechsum.dat corresponds to the information generated for each realization and displayed in seisdrv.dat. Results for these tests are included on pages 18 and 19.

George Adams 9-12-02

The test involves verifying the results in mechsum.dat at four data points:

Point 1: Repository at Drift Failure Fraction
Time: 7.60000E+02
Average: 9.46000E-01
Standard Deviation: 5.31977E-02

A hand calculation of the average and standard deviation for data retrieved
from seisdrv.dat produced the following results:

```
Realization 1: 0.92  |
Realization 2: 0.99  |
Realization 3: 0.95  | => Average = 0.946 which compares to the expected average
Realization 4: 0.87  |
Realization 5: 1.00  |

(0.92 - 0.946)**2 = 0.000676
(0.99 - 0.946)**2 = 0.001936
(0.95 - 0.946)**2 = 0.000016
(0.87 - 0.946)**2 = 0.005776
(1.00 - 0.946)**2 = 0.002916
SUM-------------- = 0.01132
SUM/(5 - 1) = 0.00283
Standard Deviation = SQRT(0.00283) = 0.053198 which compares to the expected
                                                 standard deviation
```

Point 2: Repository at the Drip Shield Failure Fraction
Time: 4.00000E+02
Average: 5.56000E-01
Standard Deviation: 1.16748E-01

A hand calculation of the average and standard deviation for data retrieved
from seisdrv.dat produced the following results:

```
Realization 1: 0.53  |
Realization 2: 0.73  |
Realization 3: 0.50  | => Average = 0.556 which compares to the expected average
Realization 4: 0.42  |
Realization 5: 0.60  |

(0.53 - 0.556)**2 = 0.000676
(0.73 - 0.556)**2 = 0.030276
(0.50 - 0.556)**2 = 0.003136
(0.42 - 0.556)**2 = 0.018496
(0.60 - 0.556)**2 = 0.001936
SUM-------------- = 0.05452
SUM/(5 - 1) = 0.01363
Standard Deviation = SQRT(0.01363) = 0.11675 which compares to the expected
                                                 standard deviation
```

George Adams 9-12-02

Point 3: Subarea 7 at the Drift Failure Fraction
Time: 5.20000E+02
Average: 4.00000E-01
Standard Deviation: 2.78887E-01

A hand calculation of the average and standard deviation for data retrieved
from seisdrv.dat produced the following results:

```
Realization 1: 0.66667  |
Realization 2: 0.33333  |
Realization 3: 0.00000  | => Average = 0.4 which compares to the expected average
Realization 4: 0.33333  |
Realization 5: 0.66667  |

(0.66667 - 0.4)**2 = 0.07111
(0.33333 - 0.4)**2 = 0.00444
(0.00000 - 0.4)**2 = 0.16
(0.33333 - 0.4)**2 = 0.00444
(0.66667 - 0.4)**2 = 0.07111
SUM--------------- = 0.3111
SUM/(5 - 1) = 0.077775
Standard Deviation = SQRT(0.077775) = 0.278882 which compares to the expected
                                                 standard deviation
```

Point 4: Subarea 8 at the Drip Shield Failure Fraction
Time: 4.80000E+02
Average: 6.75000E-01
Standard Deviation: 1.89572E-01

A hand calculation of the average and standard deviation for data retrieved
from seisdrv.dat produced the following results:

```
Realization 1: 0.500  |
Realization 2: 0.875  |
Realization 3: 0.500  | => Average = 0.675 which compares to the expected average
Realization 4: 01875  |
Realization 5: 0.625  |

(0.500 - 0.675)**2 = 0.030625
(0.875 - 0.675)**2 = 0.040000
(0.500 - 0.675)**2 = 0.030625
(0.875 - 0.675)**2 = 0.040000
(0.625 - 0.675)**2 = 0.002500
SUM--------------- = 0.14375
SUM/(5 - 1) = 0.0359375
Standard Deviation = SQRT(0.0359375) = 0.189572 which compares to the expected
                                                 standard deviation
```

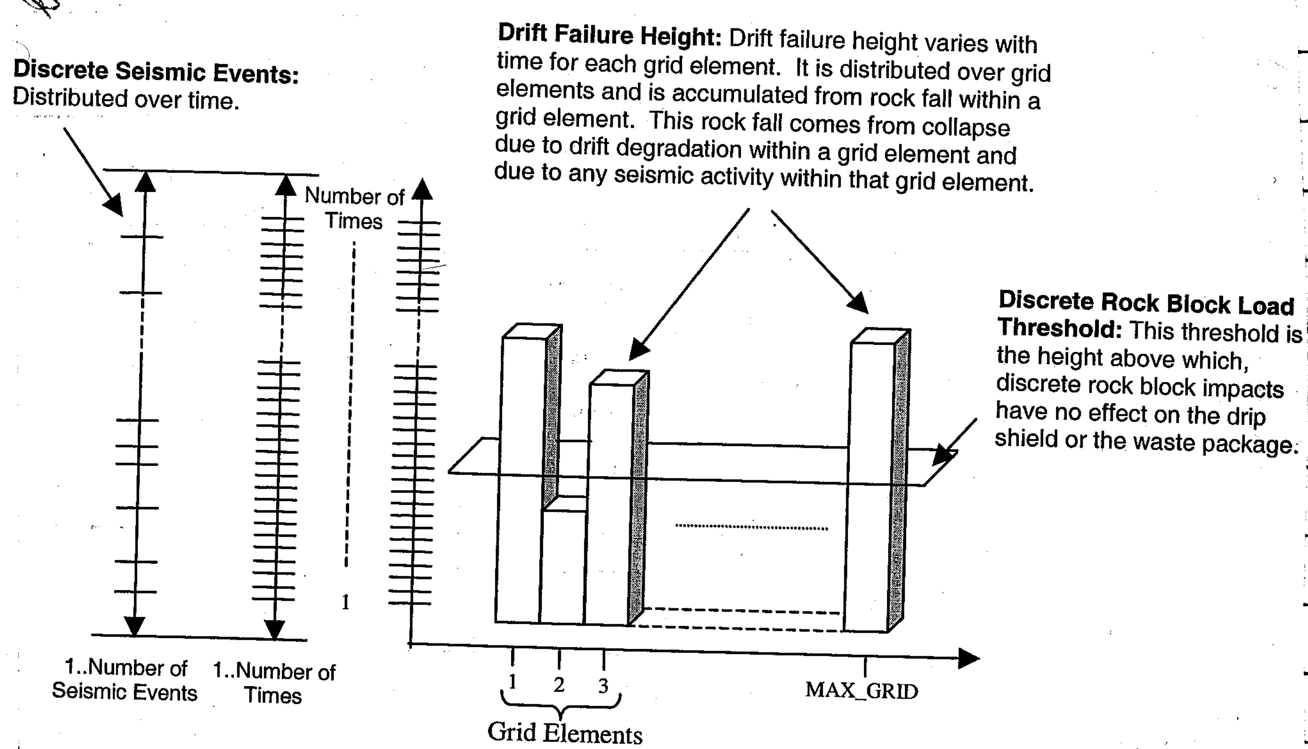
George Adams 9-12-02

9-16-02 George Adams

The update to the SEISMO Design Model is shown on the following diagram. The model was updated to include distributions for individual grid elements.

George Adams 9-16-02

Design Model



Grid Element Parameters:

Grid Elements: Two grid elements are allocated to each subarea. One grid element represents rock type one and the other represents rock type 2.

Bulking Factor: Each grid element is assigned a bulking factor. The bulking factor is used in the calculation of Discrete Rock Block Load Threshold and maximum drift failure height.

Drift Degradation Time: Drift degradation time is distributed across grid elements. The drift degradation time is used to calculate a degradation rate for each grid element.

Rock Mass Density: Rock mass density is distributed across grid elements. This density and the bulking factor are used to calculate an effective rock mass density. The effective rock mass density is then used to calculate the static load acting on the drip shield. In addition, the rock mass density is used to calculate the rock block mass for discrete rock block impacts.

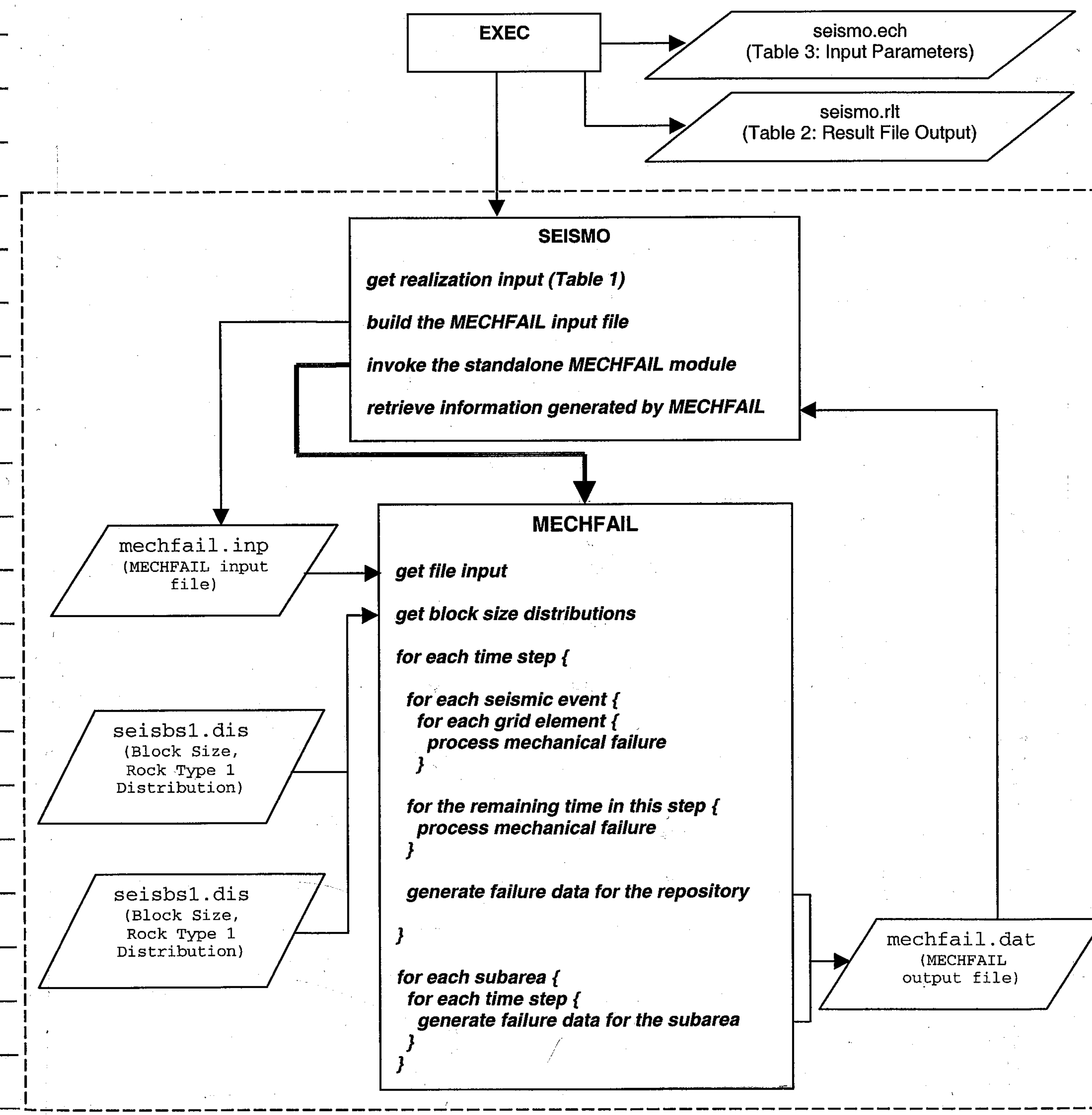
Assumptions:
1) The repository can be divided into discrete grid elements.
2) Waste package stress and strain, and drip shield stress, strain, and displacement within a grid element applies to all waste packages and drip shields within that grid element.
3) Failure within a grid element (waste package and/or drip shield) applies to all of the waste packages and/or drip shields within that grid element.

9-16-02 George Adams

The update to the SEISMO Flowchart and Data Flow Diagram is shown on the following diagram. In this design, the SEISMO module invokes the standalone module MECHFAIL.

George Adams 9-16-02

Flowchart and Data Flow Diagram



9-16-02 George Adams

The updated realization input parameters for the new SEISMO / MECHFAIL module are shown in the following table.

George Adams 9-16-02

Table 1. TPA.INP Realization Input Parameters

Parameter	Definition	Type
BulkingFactorRockTypeOneGridElement_1{2..10}[]	Bulking factor for rock type one in grid element 1{2..10}	uniform
BulkingFactorRockTypeTwoGridElement_1{2..10}[]	Bulking factor for rock type two in grid element 1{2..10}	uniform
DegradationTimeRockTypeOneGridElement_1{2..10}[yr]	Degradation time for rock type one in grid element 1 {2..10}	beta
DegradationTimeRockTypeTwoGridElement_1{2..10}[yr]	Degradation time for rock type two in grid element 1 {2..10}	beta
DripShieldBucklingLoadGridElement_1{2..10}[kg/m]	Drip shield buckling load for grid element 1{2..10}	beta
DripShieldBulkHeadCreepCoefficient[]	Creep coefficient for the drip shield bulk head	constant
DripShieldBulkHeadCreepExponent[]	Creep exponent for the drip shield bulk head	constant
DripShieldBulkHeadCreepFactor[]	Drip shield bulk head yield stress creep factor	constant
DripShieldBulkHeadFailureLogStrain[]	Drip shield bulk head failure log strain	constant
DripShieldBulkHeadYieldStress[Mpa]	Yield stress for the drip shield bulk head	constant
DripShieldCrownRadius[m]	Drip shield crown radius	constant
DripShieldHeight[m]	Height of the drip shield	constant
DripShieldPlateCreepCoefficient[]	Creep coefficient for the drip shield plate	constant
DripShieldPlateCreepExponent[]	Creep exponent for the drip shield plate	constant
DripShieldPlateCreepFactor[]	Drip shield plate yield stress creep factor	constant
DripShieldPlateFailureLogStrain[]	Drip shield plate failure log strain	constant
DripShieldPlateYieldStress[MPa]	Yield stress for the drip shield plate	constant
DripShieldToWastePackageClearance[m]	Initial clearance between the waste package and the drip shield	constant
DripShieldWidth[m]	Width of the drip shield	constant
FractionRockTypeOneInSubarea_1{2..10}[]	Fraction of rock type one in the subarea	constant
GroundAccelerationInitialRockTypeOneGridElement_1{2..10}[pga]	Plastic failure zone curve parameter. Initial point on curve for ground acceleration of rock type one in grid element 1{2..10}	beta
GroundAccelerationInitialRockTypeTwoGridElement_1{2..10}[pga]	Plastic failure zone curve parameter. Initial point on curve for ground acceleration of rock type two in grid element 1{2..10}	beta
GroundAccelerationMaximumRockTypeOneGridElement_1{2..10}[pga]	Plastic failure zone curve parameter. Maximum point on curve for ground acceleration of rock type one in grid element 1{2..10}	beta
GroundAccelerationMaximumRockTypeTwoGridElement_1{2..10}[pga]	Plastic failure zone curve parameter. Maximum point on curve for ground acceleration of rock type two in grid element 1{2..10}	beta
InvertHeight[m]	Invert height	constant
NumberOfBlockSizePoints[]	Number of values in files seisbs1.dis and seisbs2.dis	constant
RockMassDensityForRockTypeOne[kg/m^3]	Rock type one rock mass density	constant
RockMassDensityForRockTypeTwo[kg/m^3]	Rock type two rock mass density	constant
SeedForRandomNumberForSEISMO	A random number seed for sampling the time and magnitude of seismic events	constant
SeismicHazardCurveforSEISMO	Minimum peak ground acceleration for bins, return period (yr); number of magnitudes for recurrence of seismic events, magnitude, and recurrence time	hazardcurve
StartingBlockPointerOne[]	Pointer for the starting point in the rock type one block size distribution	uniform
StartingBlockPointerTwo[]	Pointer for the starting point in the rock type two block size distribution	uniform
WastePackageOuterBarrierFailureLogStrain[]	Waste package outer barrier failure log strain	constant
WastePackageOuterBarrierYieldStress[MPa]	Waste package outer barrier yield stress	constant

9-16-02 George Adams

Parameters which are written out to the SEISMO result file (SEISMO.RLT) and SEISMO echo file (SEISMO.ECH) are shown in the following two tables.

George Adams 9-16-02

Table 2. SEISMO.RLT Parameter Definitions

Parameter	Definition
accumDSFailureSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the drip shields that have failed in each subarea
accumDSFailureTotal(1..maxNumTime)	Accumulated fraction of the drip shields that have failed in the repository
accumWPFailureSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the waste packages that have failed in each subarea
accumWPFailureTotal(1..maxNumTime)	Accumulated fraction of the waste packages that have failed in the repository
dsBuckling(1..maxNumTime)	Accumulated fraction of the drip shields that have failed by buckling in the repository
dsBucklingSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the drip shields that have failed by buckling in each subarea
dsBulkHead(1..maxNumTime)	Accumulated fraction of the drip shields that have failed by bulk head failure in the repository
dsBulkHeadSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the drip shields that have failed by bulk head failure in each subarea
dsPlate(1..maxNumTime)	Accumulated fraction of the drip shields that have failed by plate failure in the repository
dsPlateSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the drip shields that have failed by plate failure in each subarea
fractionDriftCollapseSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of collapsed drifts in each subarea
fractionDriftCollapseTotal(1..maxNumTime)	Accumulated fraction of collapsed drifts in the repository
fractionGrid(1..numSubareas)	Fraction of the repository ground coverage in each subarea
sccBottom(1..maxNumTime)	Accumulated fraction of the waste packages experiencing stress corrosion cracking at the bottom in the repository
sccBottomSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the waste packages experiencing stress corrosion cracking at the bottom in each subarea
sccTop(1..maxNumTime)	Accumulated fraction of the waste packages experiencing stress corrosion cracking at the top in the repository
sccTopSubarea((1..maxNumTime, 1..numSubareas)	Accumulated fraction of the waste packages experiencing stress corrosion cracking at the top ine each subarea
wpBottom(1..maxNumTime)	Accumulated fraction of the waste packages that have failed at the bottom in the repository
wpBottomSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the waste packages that have failed at the bottom in each subarea
wpTop(1..maxNumTime)	Accumulated fraction of the waste packages that have failed at the top in the repository
wpTopSubarea(1..maxNumTime, 1..numSubareas)	Accumulated fraction of the waste packages that have failed at the top in each subarea

George Adams 9-16-02

Table 3. SEISMO.ECH Parameter Definitions

Parameter	Definition
dsThickness(1..maxNumTime)[m]	Drip shield thickness at each of the TPA time steps
numTime	Number of TPA time steps
time(1..maxNumTime)[yr]	Time for each of theTPA time steps
timeSeismicEvents(1..numSeismicEvents)[yr]	Time that each seismic event occurs
typeSeismicEvents(1..numSeismicEvents)[pga]	Peak ground acceleration associated with each of the seismic events

9-24-02 George Adams

The SEISMO/MECHFAIL code modules assign a drift degradation time to each grid element. The drift degradation time is represented using a beta distribution with parameters defined as follows: A=0.0, B=1000.0, p=5.85392, q=2.21348.

George Adams 9-24-02

■ Td

Note skewed left here.

mode and 80 percentile after normalization

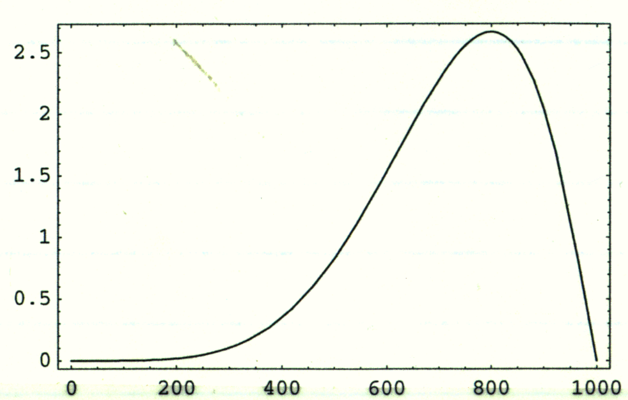
```
In[81]:= xmin = 0;
         xmax = 1000;
         xmode = 800;
         x80 = 600;

In[85]:= xmode = (xmode - xmin) / (xmax - xmin);
         x80 = (x80 - xmin) / (xmax - xmin);
         {xmode, x80}

Out[87]= {4/5, 3/5}
```

alpha parameter

```
In[88]:= ahat =
           a /. FindRoot[BetaRegularized[x80, a, (-1 + a + 2 xmode - a xmode)/xmode] == 0.2, {a, 1.1}]

Out[88]= 5.85392
```

beta parameter

```
In[89]:= bhat = (-1 + ahat + 2 xmode - ahat xmode)/xmode

Out[89]= 2.21348

In[90]:= Plot[ PDF[BetaDistribution[ ahat, bhat] , (x - xmin) / (xmax - xmin)],
          {x, xmin, xmax}, Frame → True]
```




```
Out[90]= - Graphics -
```


9-24-02 George Adams

The SEISMO/MECHFAIL code modules assign a ground acceleration initial beta distribution to each grid element. This beta distribution is defined with the following parameters: A= 0.2, B = 0.3, p= 2.21348, q= 5.85392.

George Adams 9-24-02

■ g0

mode and 80 percentile after normalization

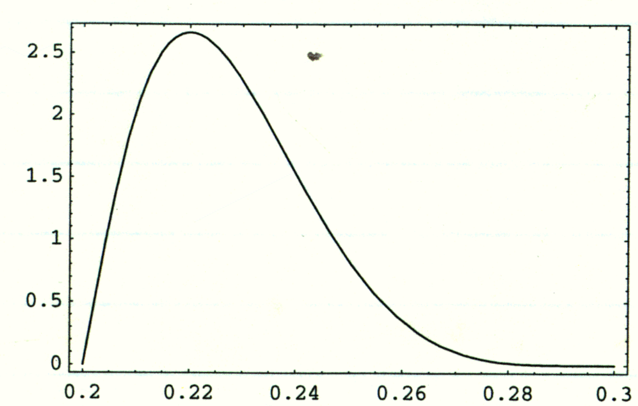
```
In[20]:= xmax = 0.3;
         xmin = 0.2;
         xmode = 0.22;
         x80 = 0.24;

In[24]:= xmode = (xmode - xmin) / (xmax - xmin);
         x80 = (x80 - xmin) / (xmax - xmin);
         {xmode, x80}

Out[26]= {0.2, 0.4}
```

alpha parameter

```
In[27]:= ahat =
           a /. FindRoot[BetaRegularized[x80, a, (-1 + a + 2 xmode - a xmode)/xmode] == 0.8, {a, 1.2}]

Out[27]= 2.21348
```

beta parameter

```
In[28]:= bhat = (-1 + ahat + 2 xmode - ahat xmode)/xmode

Out[28]= 5.85392

In[29]:= Plot[ PDF[BetaDistribution[ ahat, bhat] , (x - xmin) / (xmax - xmin)],
          {x, xmin, xmax}, Frame → True]
```




```
Out[29]= - Graphics -
```

9-24-02 George Adams

The SEISMO/MECHFAIL code modules assign a ground acceleration maximum beta distribution to each grid element. The beta distribution is defined with the following parameters: A = 1.0, B = 2.0, p = 2.79439, q = 17.1495.

■ gmax

George Adams 9-24-02

mode and 80 percentile after normalization

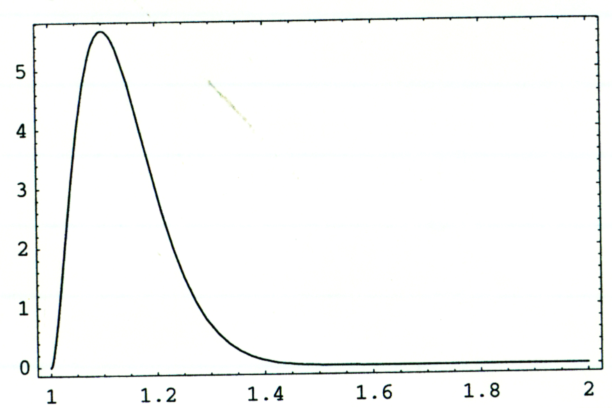
```
In[2]:= xmax = 2;
        xmin = 1.;
        xmode = 1.1;
        x80 = 1.2;

In[6]:= xmode = (xmode - xmin) / (xmax - xmin);
        x80 = (x80 - xmin) / (xmax - xmin);
        {xmode, x80}

Out[8]= {0.1, 0.2}
```

alpha parameter

```
In[9]:= ahat = a /. FindRoot[BetaRegularized[x80, a, (-1 + a + 2 xmode - a xmode)/xmode] == 0.8, {a, 1.2}]

Out[9]= 2.79439
```

beta parameter

```
In[10]:= bhat = (-1 + ahat + 2 xmode - ahat xmode)/xmode

General::spell1 : Possible spelling error: new symbol name "bhat" is similar to existing symbol "ahat".

Out[10]= 17.1495

In[12]:= Plot[PDF[BetaDistribution[ahat, bhat], (x - xmin) / (xmax - xmin)],
          {x, xmin, xmax}, Frame → True, PlotRange → All]
```




```
Out[12]= - Graphics -
```


9-24-02 George Adams

The SEISMO/MECHFAIL code modules assign a drip shield buckling load to each grid element that is independent of rock type. The drip shield buckling load is represented by a beta distribution with parameters defined as follows: A = 15000, B = 150000, p = 2.89721, q = 9.34772.

■ Fs

George Adams 9-24-02

mode and 80 percentile after normalization

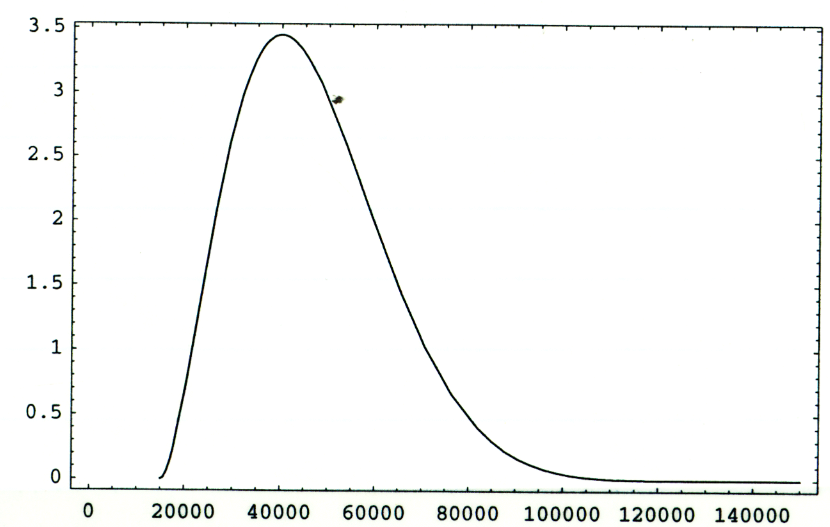
```
xmax = 150000;
xmin = 15000;
xmode = 40000;
x80 = 60000;

xmode = (xmode - xmin) / (xmax - xmin);
x80 = (x80 - xmin) / (xmax - xmin);
{xmode, x80}

{5/27, 1/3}
```

alpha parameter

```
ahat = a /. FindRoot[BetaRegularized[x80, a, (-1 + a + 2 xmode - a xmode)/xmode] == 0.8, {a, 1.2}]

2.89721
```

beta parameter

```
bhat = (-1 + ahat + 2 xmode - ahat xmode)/xmode

9.34772

Plot[PDF[BetaDistribution[ahat, bhat], (x - xmin) / (xmax - xmin)],
 {x, xmin, xmax}, Frame → True]
```




```
- Graphics -
```

9-24-02 George Adams

The SEISMO/MECHFAIL code modules assign bulking factors to grid elements using a uniform distribution. The uniform distribution is defined with the following parameters: A = 1.15, B = 1.35

9-24-02 George Adams

For a seismic event, rock block volumes are sampled in accordance with the following distributions (BlockSize1 corresponds to rock type 1, BlockSize2 corresponds to rock type 2).

George Adams 9-24-02

```
TITLE - seisblk
RANDOM SEED          -188910452
NOBS                 10000
NREPS  1
USER SUPPLIED PIECE-WISE CDF          BlockSize1

                8
   0.00000E+00    0.00000E+00
   0.00000E+00    1.91480E-02
   0.00000E+00    1.08357E-01
   0.00000E+00    5.42860E-01
   0.00000E+00    8.08339E-01
   0.00000E+00    9.26897E-01
   0.00000E+00    9.76288E-01
   0.00000E+00    1.00000E+00
USER SUPPLIED PIECE-WISE CDF          BlockSize2

                8
   0.00000E+00    0.00000E+00
   2.50000E-01    1.91480E-02
   5.00000E-01    1.08357E-01
   1.00000E+00    5.42860E-01
   2.00000E+00    8.08339E-01
   4.00000E+00    9.26897E-01
   8.00000E+00    9.76288E-01
   1.60000E+01    1.00000E+00
```

George Adams 9-24-02

9-24-02 George Adams

For the new SEISMO/MECHFAIL code, the seismic hazard curve was redefined with the following parameters:

Peak Ground Acceleration (PGA)	Return Period
0.05	100.0
0.09	316.2
0.18	1000.0
0.33	3162.0
0.54	10000.0
0.87	31620.0
1.33	100000.0
1.88	316200.0
3.0	1000000.0
6.0	100000000.0

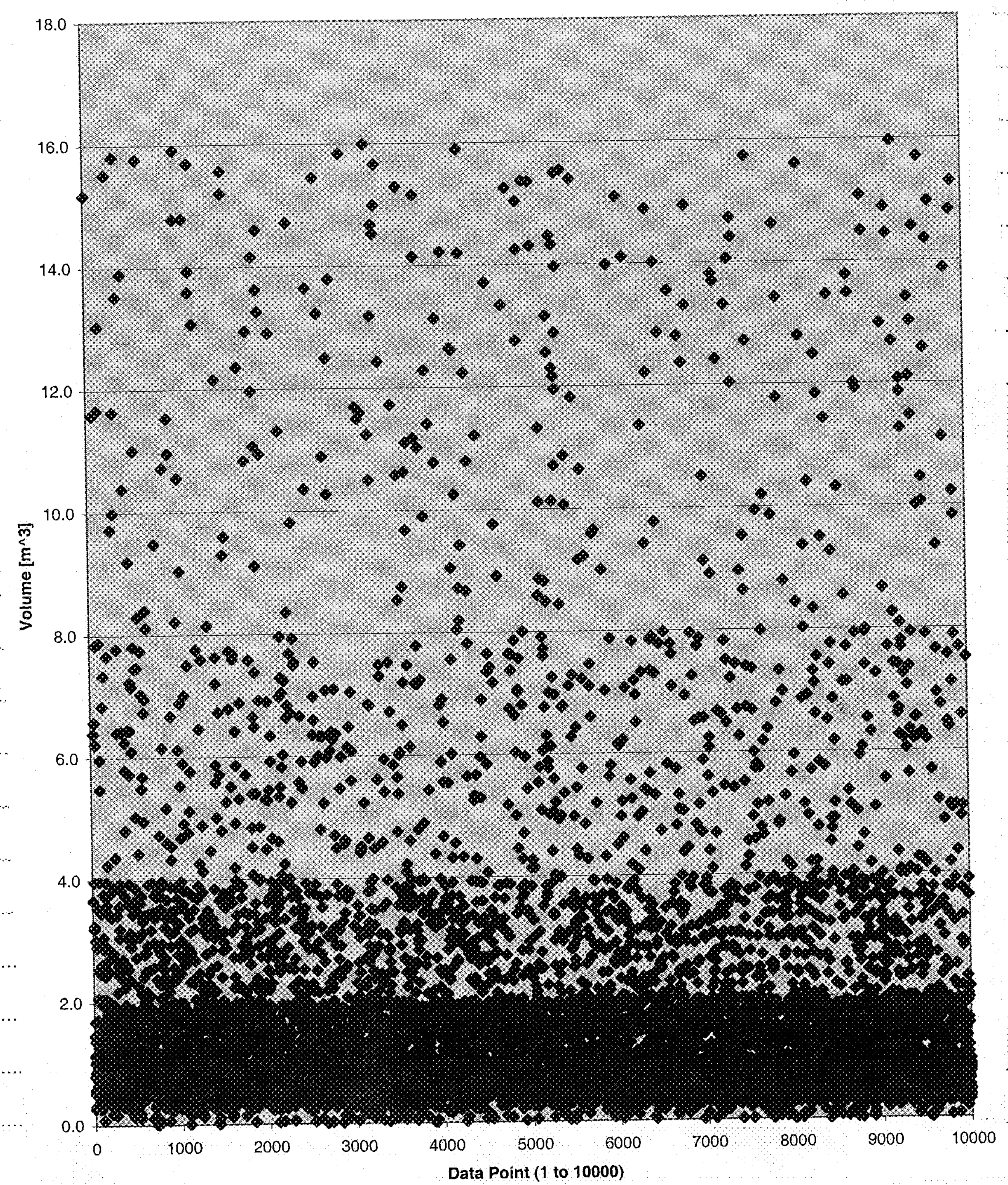
George Adams 9-24-02

9-24-02 George Adams

The BlockSize2 rock block volume distribution is shown on the following scatter plot: (The User Supplied Piece-Wise CDF was defined with input parameters shown on page 28)

Discrete Rock Block Volumes (Rock Type 2)

George Adams 9-24-02



9-24-02 George Adams

An analysis was performed on Drift and Dripshield Failure Fraction (average and standard deviation) versus number of grid elements (grid points) for subarea 1 of the repository. The test was performed over 10,000 years using 100 realizations. The output summary data is tabulated as follows:

George Adams 9-24-02

Subarea 1 Analysis at 520 years

Number of Grid Elements	Drift Failure Average	Drift Failure Standard Deviation	Drip Shield Failure Average	Drip Shield Failure Standard Deviation
2	0.2700	0.3211	0.7400	0.3294
4	0.2850	0.2331	0.7250	0.2147
5	0.2660	0.2090	0.7340	0.1821
8	0.2838	0.1953	0.7225	0.1575
10	0.2790	0.1552	0.7270	0.1483
20	0.2760	0.1232	0.7370	0.1093
30	0.2767	0.1225	0.7300	0.0863
40	0.2795	0.1206	0.7250	0.0900
Overall Average	0.2770		0.7301	

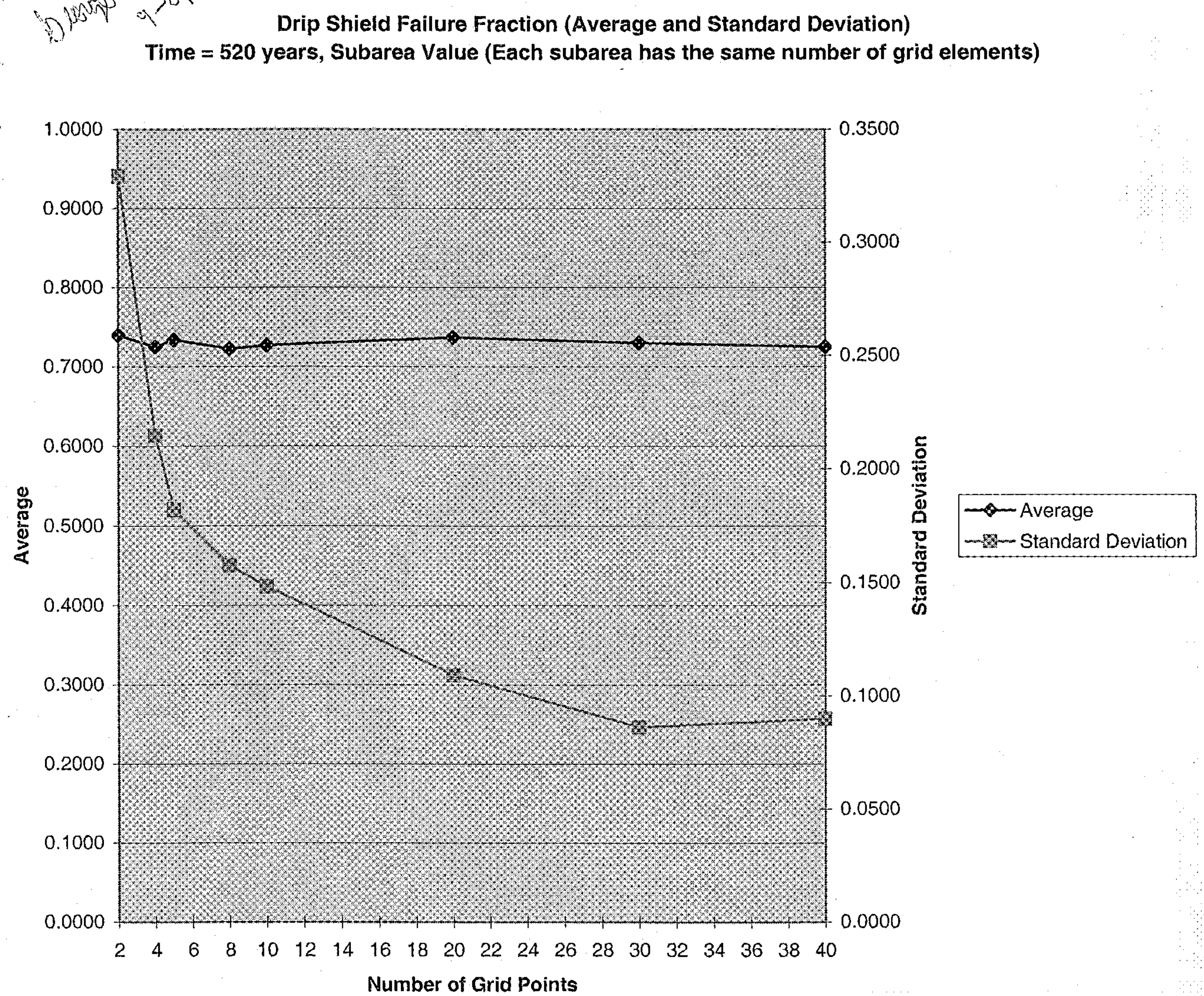
Number of Grid Elements	Percentage Difference	Percentage Difference
2	-2.52%	1.36%
4	2.89%	-0.69%
5	-3.97%	0.54%
8	2.44%	-1.04%
10	0.73%	-0.42%
20	-0.36%	0.95%
30	-0.12%	-0.01%
40	0.91%	-0.69%

George Adams 9-24-02

9-24-02 George Adams

The drip shield failure fraction (average and standard deviation) versus number of grid points is shown on the following plot:

George Adams 9-24-02

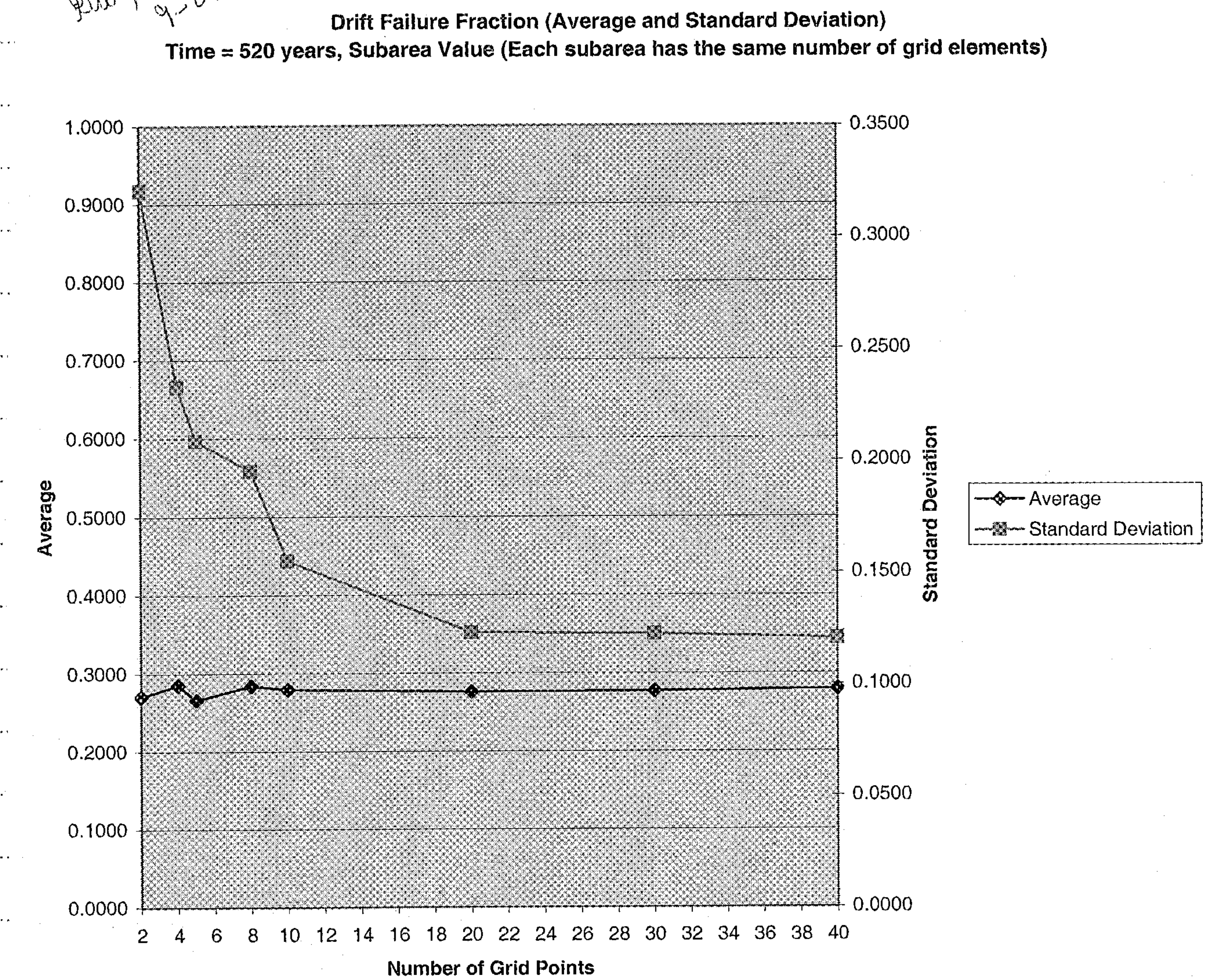


George Adams 9-24-02

9-24-02 George Adams

The drift failure fraction (average and standard deviation) versus number of grid points is shown on the following plot:

George Adams 9-24-02



George Adams 9-24-02

9-24-02 George Adams

The following code modifications were made to retrieve sampled results over a large number of grid elements and large number of realizations. In addition, subroutine BETAD in module snllhs.f was modified to eliminate an array index out of bounds error when SAMPLE(0) was retrieved.

George Adams 9-24-02

```
Modification made to subroutine BETAD in module snllhs.f

c       GADAMS PA-SCR-385 8-30-02: Changed the following line to bound
c       the index between 1 and NOBS
c        X(LOC(I,J)) = A + (B-A)*(SAMPLE(NINT(R*NOBS)))
        X(LOC(I,J)) = A + (B-A)*(SAMPLE(1 + NINT(R*(NOBS -1))))

Modifications to module lhs1.i

c     GADAMS PA-SCR-385 9-20-02: Modified this parameter to 10000 to
allow
c     10000 realizations.  This modification is used to generate block
c     size distributions with 10000 points.
c      PARAMETER (NMAX=4000)
      PARAMETER (NMAX=10000)
c     GADAMS PA-SCR-385 9-20-02: End of change
c
c     GADAMS PA-SCR-385 8-29-02: For sensitivity analysis, it is
necessary to
c     increase the number of variables allowed to encompass a large
number
c     of grid elements
c      PARAMETER (NVAR=500)
      PARAMETER (NVAR=2500)
```

George Adams 10-31-02

10-31-02 George Adams

Performed a Seismic Hazard Curve analysis using TPA code version 5.0 Beta. The purpose of this analysis was to generate the recurrence time (the time in years between successive seismic events) and the peak ground acceleration versus time of occurrence.

An analysis was performed over 10,000 years resulting in 64 seismic events over these 10,000 years. Modifications were made to TPA.INP in accordance with the following:

George Adams 10-31-02

Analysis Performed: **10-30-02 to 10-31-02**
Data Extracted from File: seismo10k50beta.ech
Analysis performed using TPA 5.0Beta
Modifications to TPA.INP: SeismicHazardCurveforSEISMO

0.050	142.0
0.100	409.0
0.169	1000.0
0.350	3968.0
0.534	10000.0
0.750	22340.0
1.305	100000.0
2.000	336261.0
3.000	1158062.0
6.000	100000000.0

Number of Events = 64

George Adams 10-31-02

10-31-02 [signature]

An additional Seismic Hazard Curve analysis was performed over 100,000 years. This analysis resulted in 697 events occurring over the 100,000 year analysis period. As part of this analysis, modifications were made to the code 5.0 Beta TPA.INP file in accordance with the following:

[signature] 10-31-02

Analysis Performed: 10-30-02 to 10-31-02
Data Extracted from File: seismo100k50beta.ech
Analysis performed using TPA 5.0Beta
Modifications to TPA.INP:

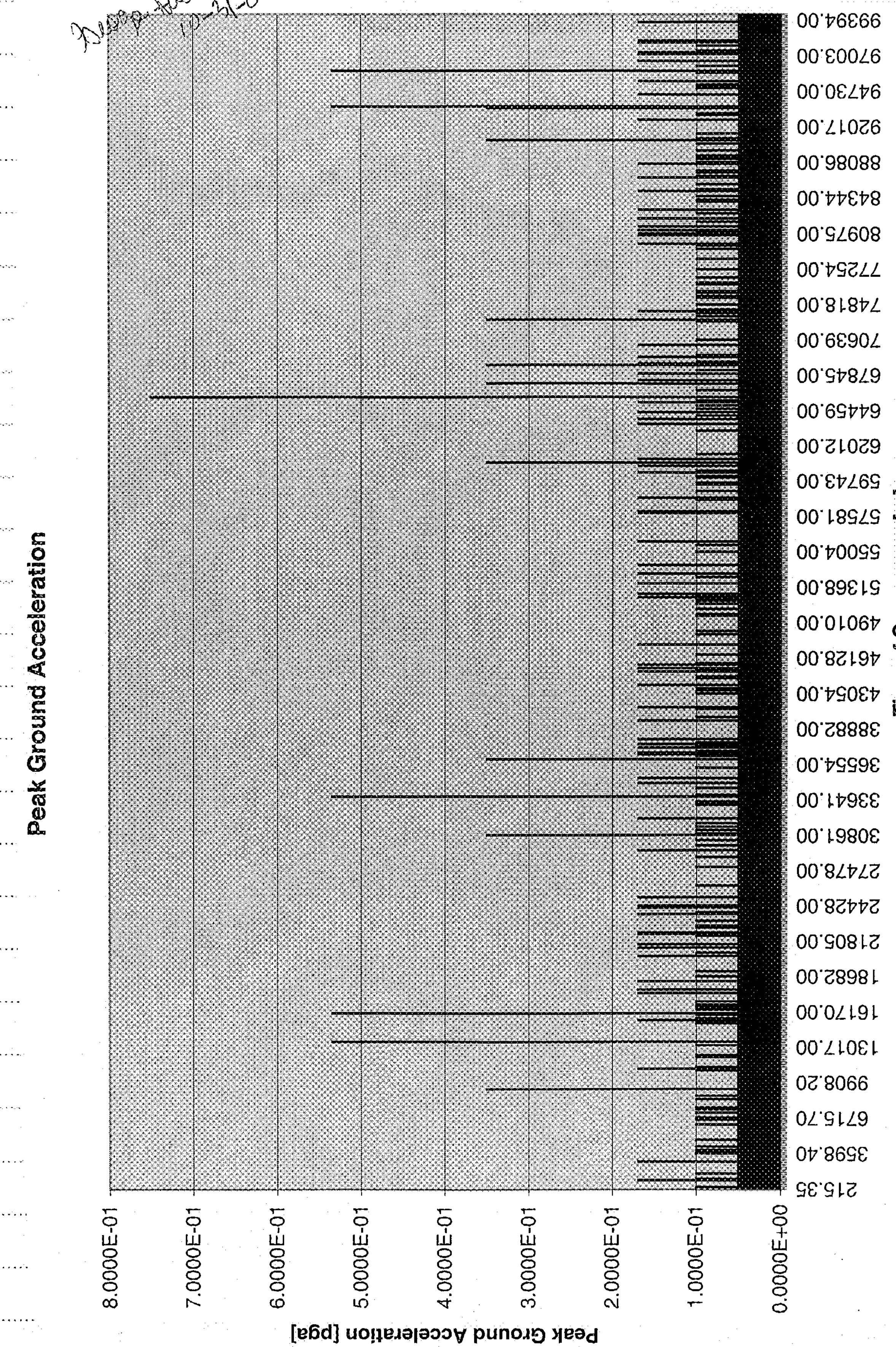
MaximumTime[yr]	1.0000E+05
SeismicHazardCurveforSEISMO	
0.050	142.0
0.100	409.0
0.169	1000.0
0.350	3968.0
0.534	10000.0
0.750	22340.0
1.305	100000.0
2.000	336261.0
3.000	1158062.0
6.000	100000000.0

Number of Events = 697

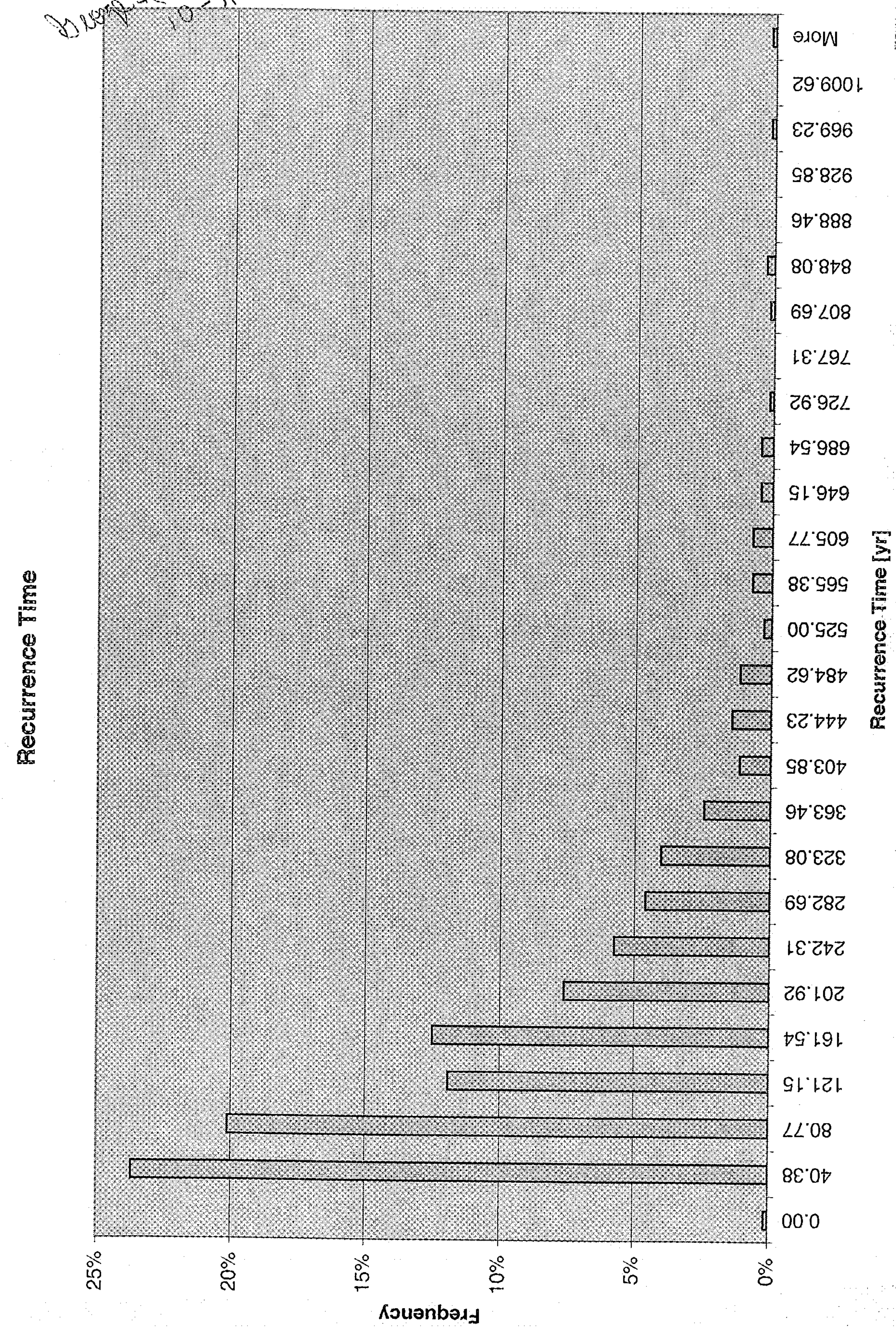
10-31-02 [signature]

The results from the 100,000 year Seismic Hazard Curve analysis were extracted from seismo.ech and plotted as peak ground acceleration versus ~~tie~~ [signature] 10-31-02 time of occurrence on page 37 with the frequency (percent) versus recurrence time plotted on page 38.

[signature] 10-31-02



George Adams 10-31-02

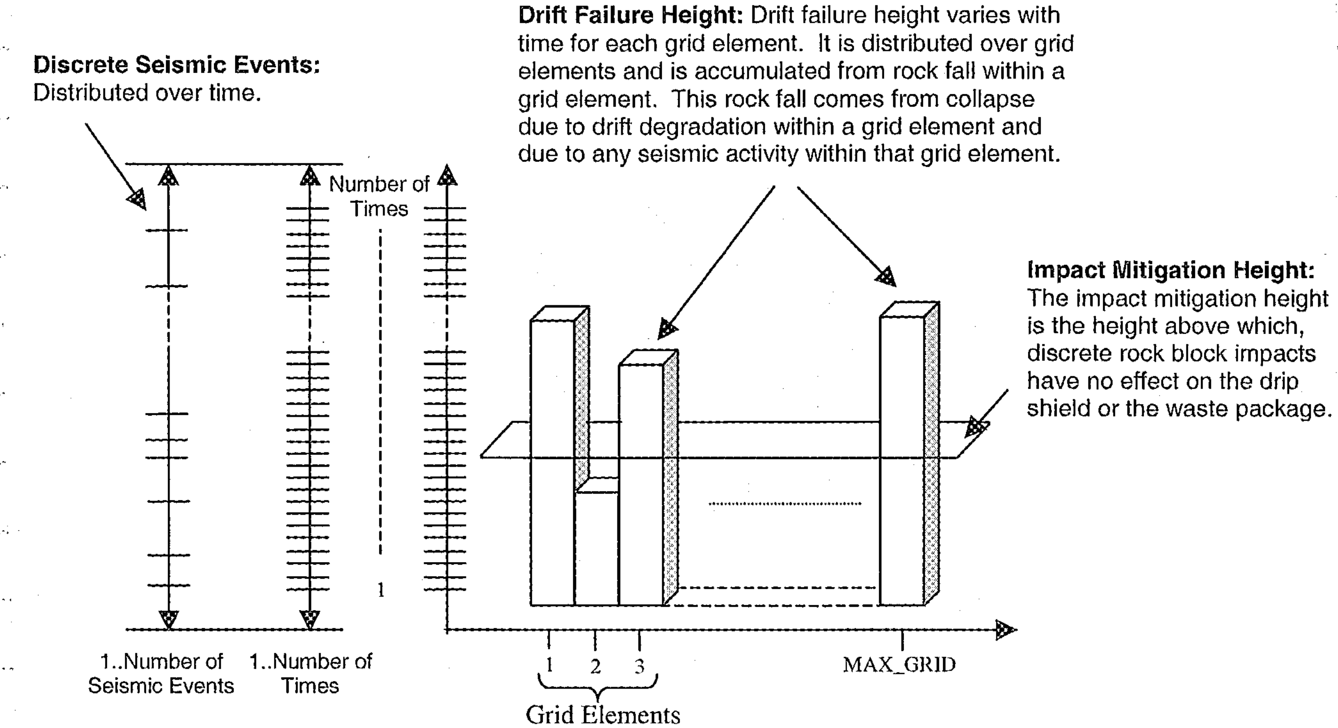


11-11-02 George Adams

The design model from page 20 was updated to refer to Impact Mitigation Height.

Design Model

George Adams 11-1-02



Grid Element Parameters:

Grid Elements: Two grid elements are allocated to each subarea. One grid element represents rock type one and the other represents rock type 2.

Bulking Factor: Each grid element is assigned a bulking factor. The bulking factor is used in the calculation of Impact Mitigation Height and maximum drift failure height.

Drift Degradation Time: Drift degradation time is distributed across grid elements. The drift degradation time is used to calculate a degradation rate for each grid element.

Rock Mass Density: Rock mass density is distributed across grid elements. This density and the bulking factor are used to calculate an effective rock mass density. The effective rock mass density is then used to calculate the static load acting on the drip shield. In addition, the rock mass density is used to calculate the rock block mass for discrete rock block impacts.

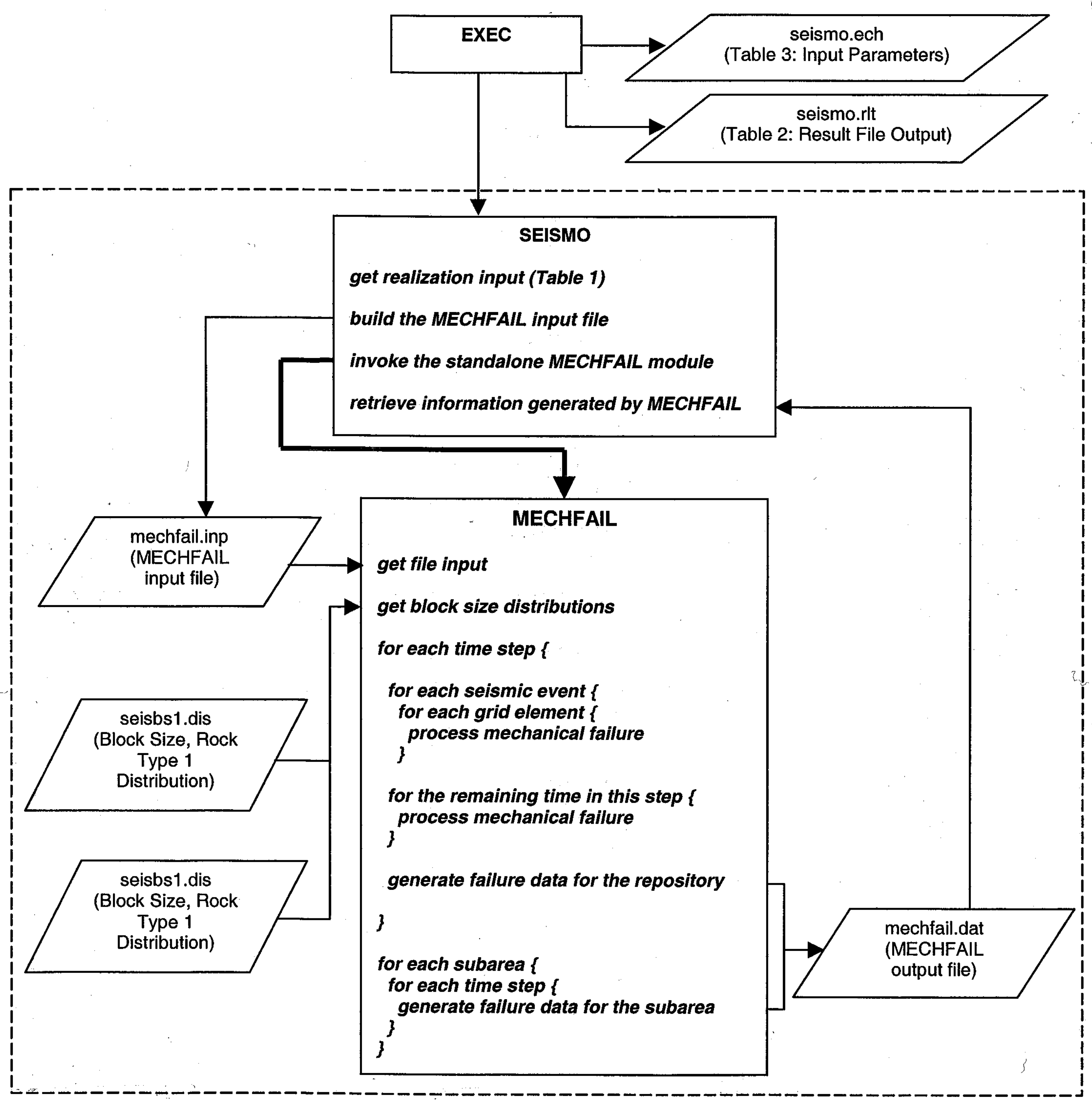
Assumptions:

1) The repository can be divided into discrete grid elements.
2) Waste package stress and strain, and drip shield stress, strain, and displacement within a grid element applies to all waste packages and drip shields within that grid element.
3) Failure within a grid element (waste package and/or drip shield) applies to all of the waste packages and/or drip shields within that grid element.

11-11-02 George Adams

The flowchart below shows, from a high level, the interaction between the TPA Executive and the SEISMO / MECHFAIL modules.

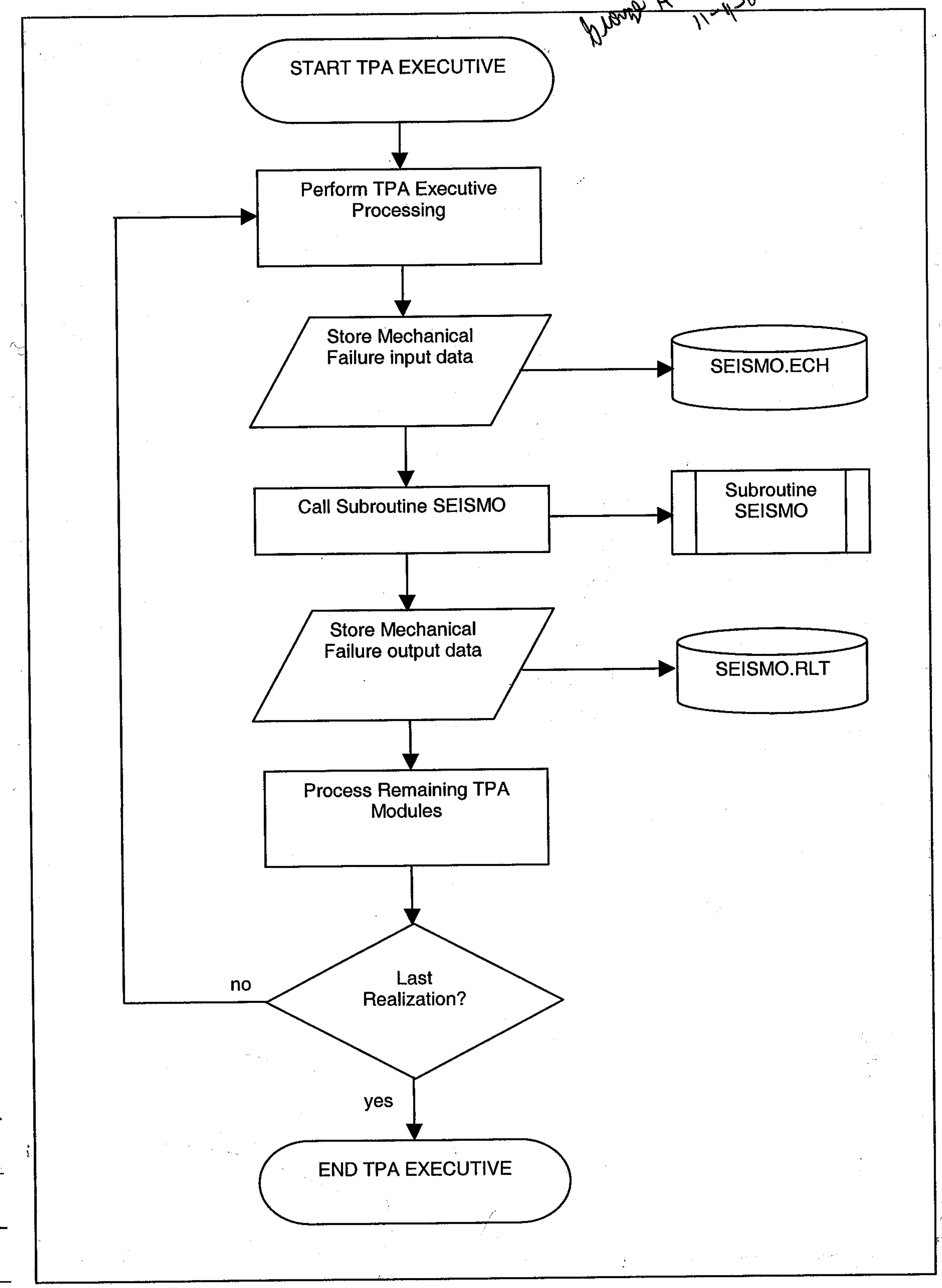
Flowchart and Data Flow Diagram George Adams 11-11-02



11-11-02 George Adams

The flowchart below shows the TPA Executive invoking the SEISMO Subroutine.

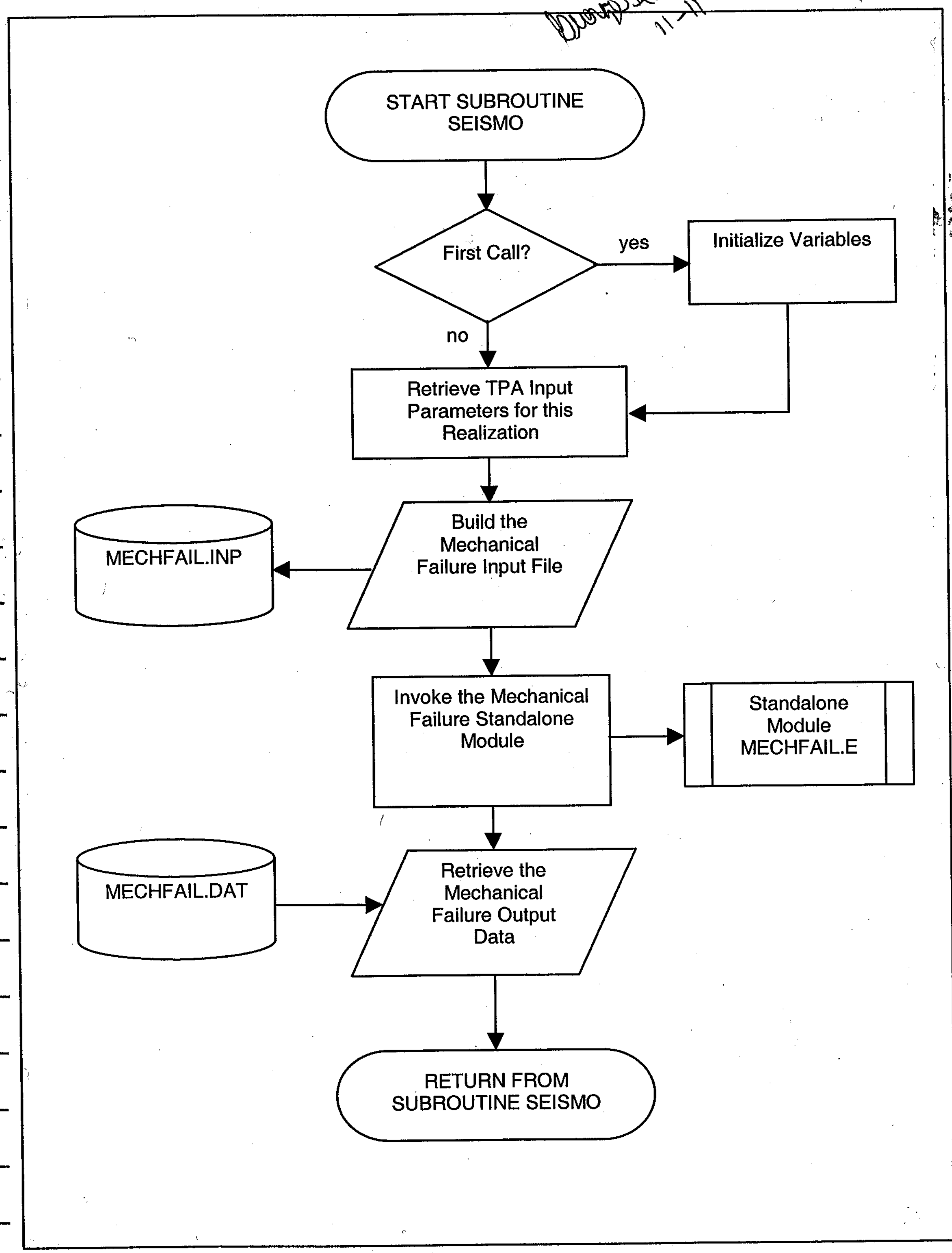
George Adams 11-4-02



11-11-02 George Adams

The flowchart below shows the execution of the SEISMO Subroutine.

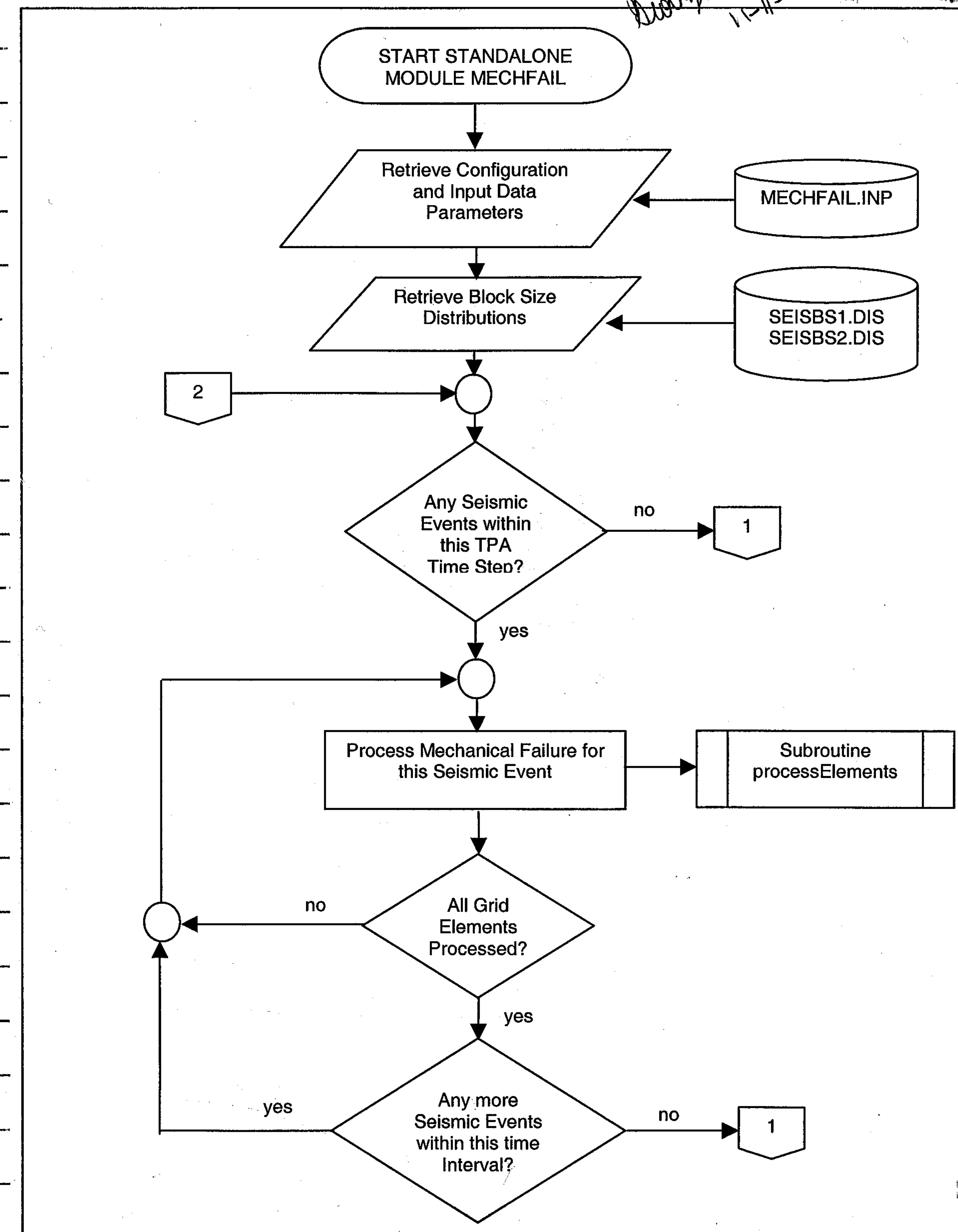
George Adams 11-11-02



11-11-02 George Adams

The flowchart on this page and page 44 show the execution of standalone module MECHFAIL.

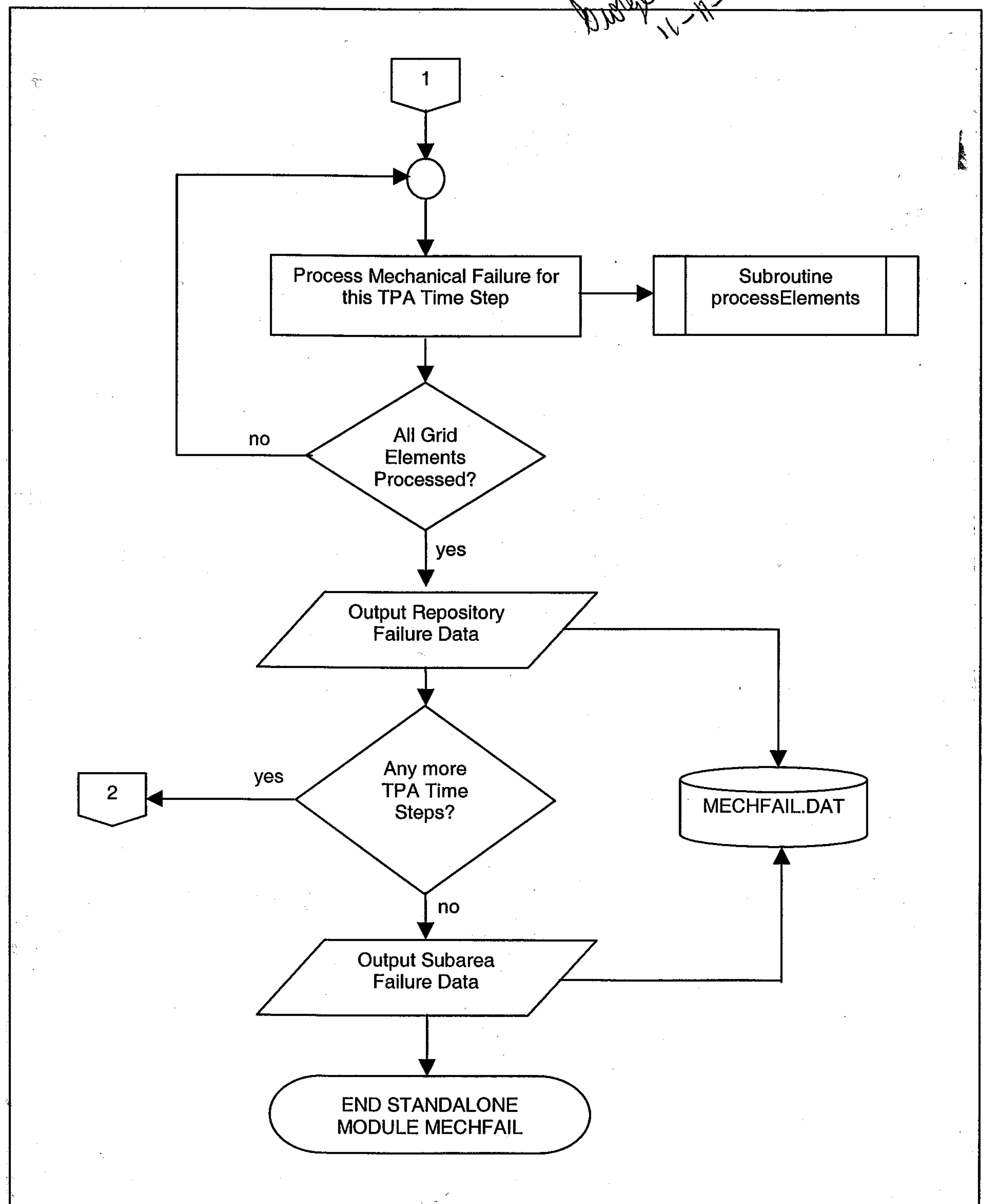
George Adams 11-11-02



11-11-02 George Adams

The flowchart below is a continuation of the MECHFAIL module started on page 43.

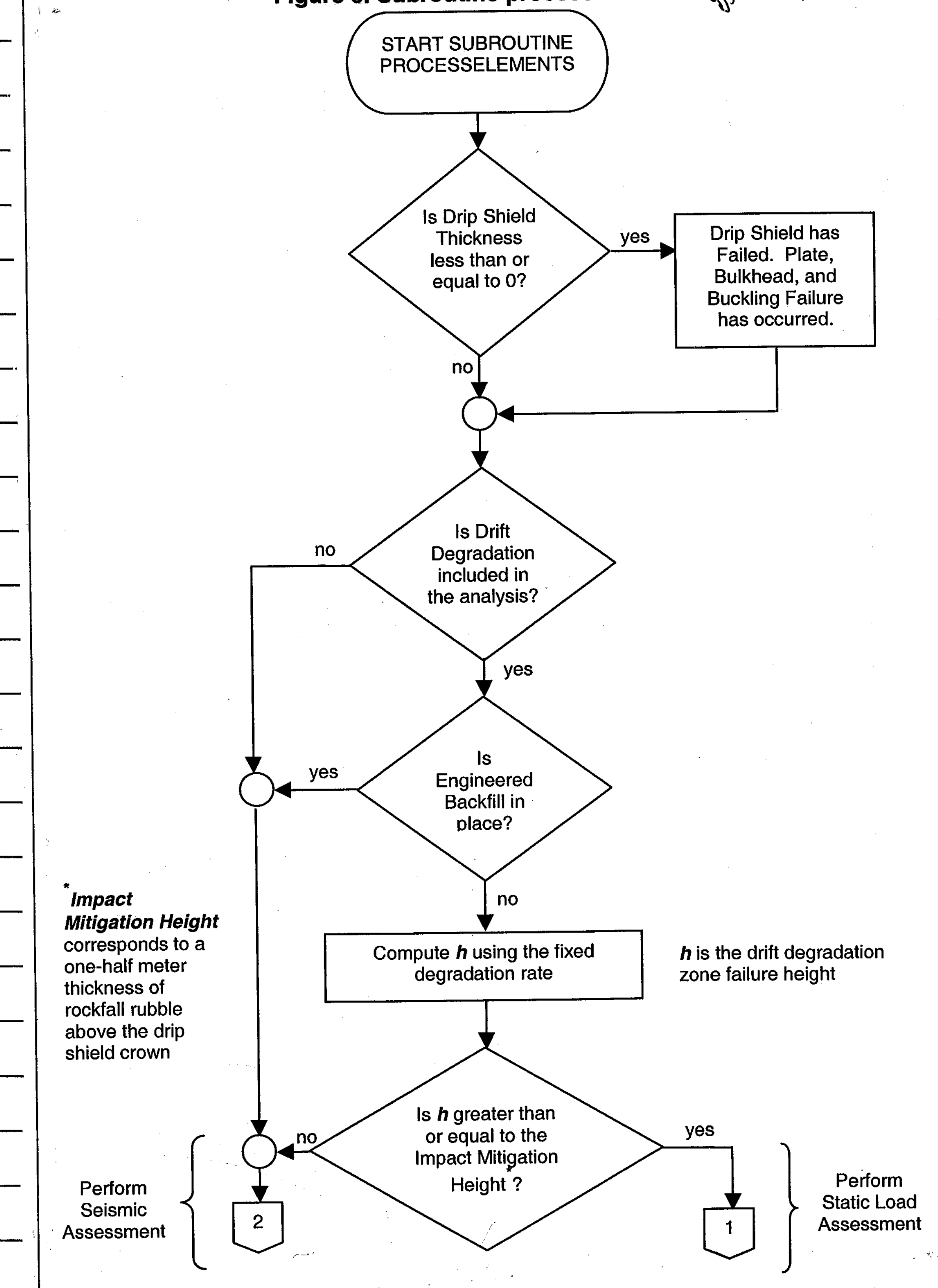
George Adams 11-11-02



11-11-02 George Adams The flowchart below is the first of a series of flowcharts for subroutine process Elements of MECHFAIL.

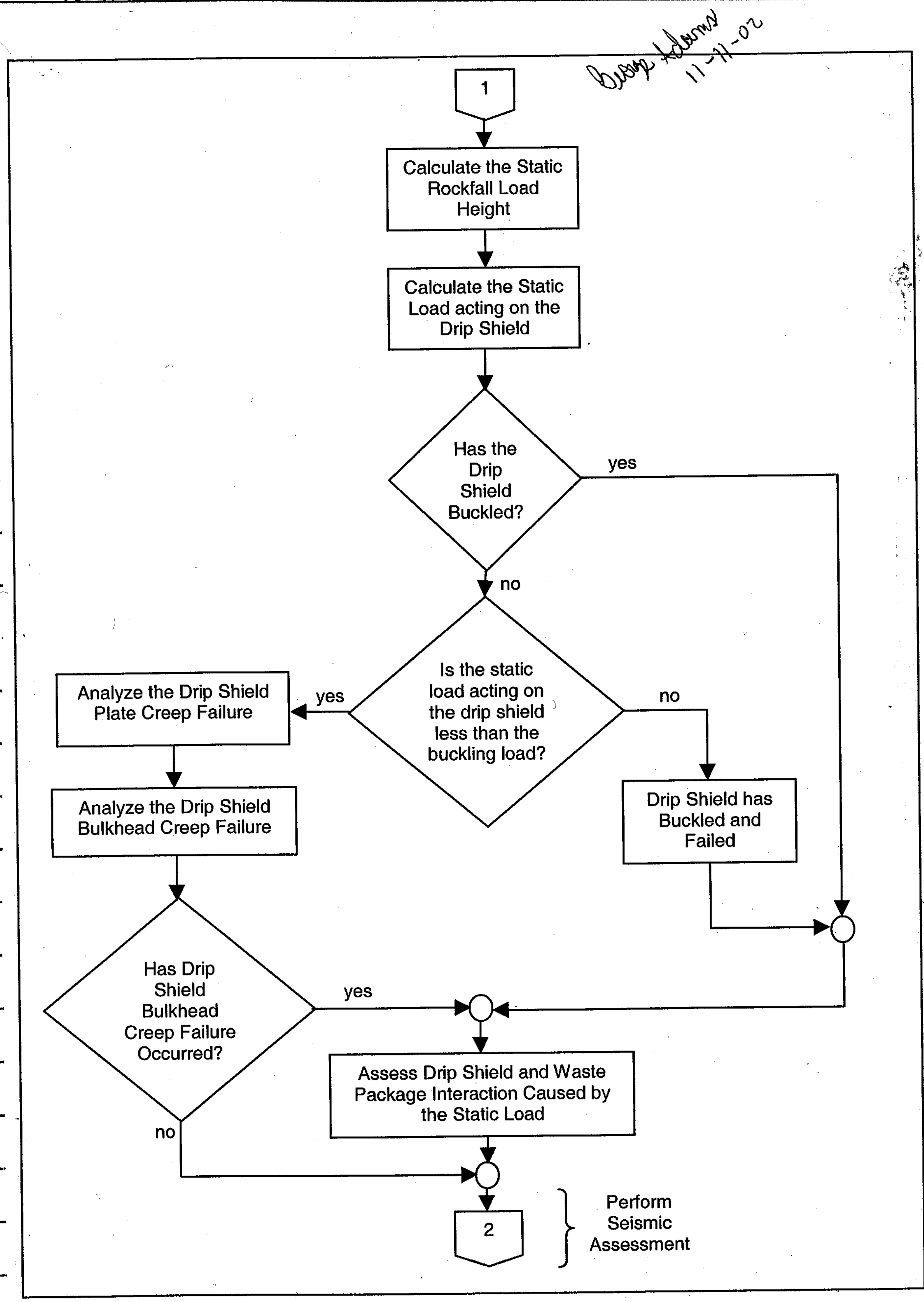
Figure 5. Subroutine processElements

George Adams 11-11-02



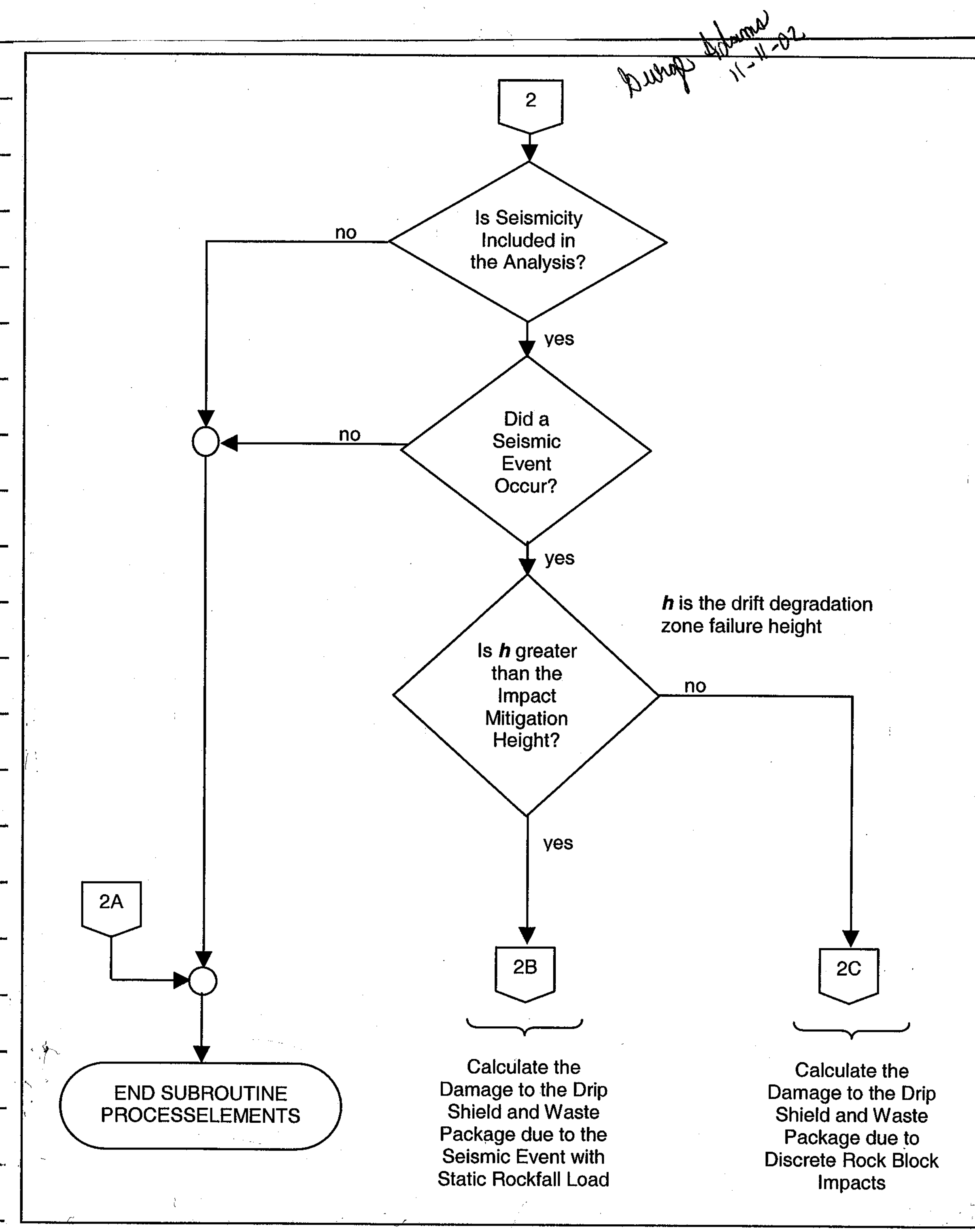
11-11-02 George Adams

The flowchart below shows the static load assessment within subroutine processElements.



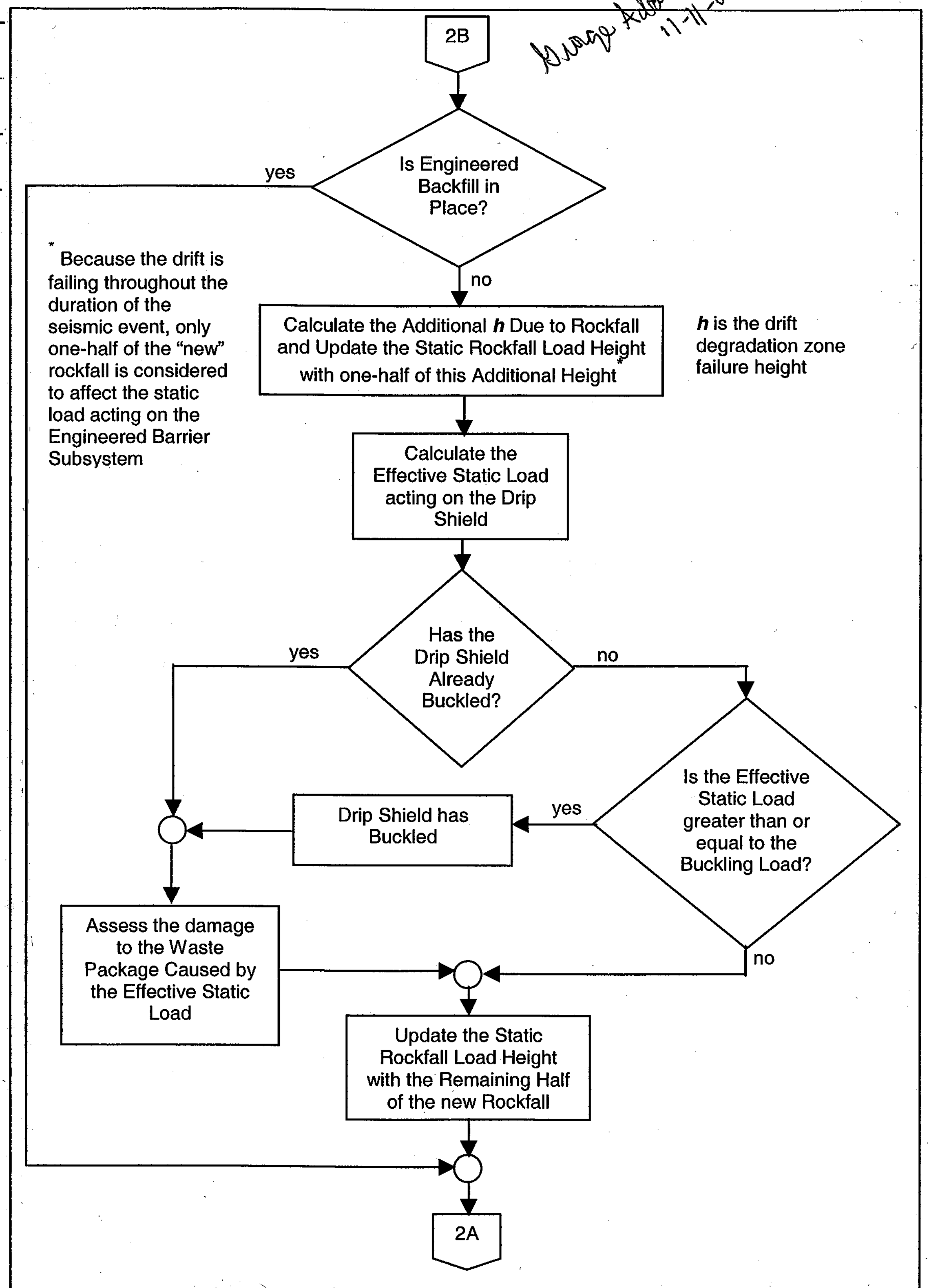
11-11-02 George Adams

The flowchart below shows the seismic assessment within subroutine processElements.



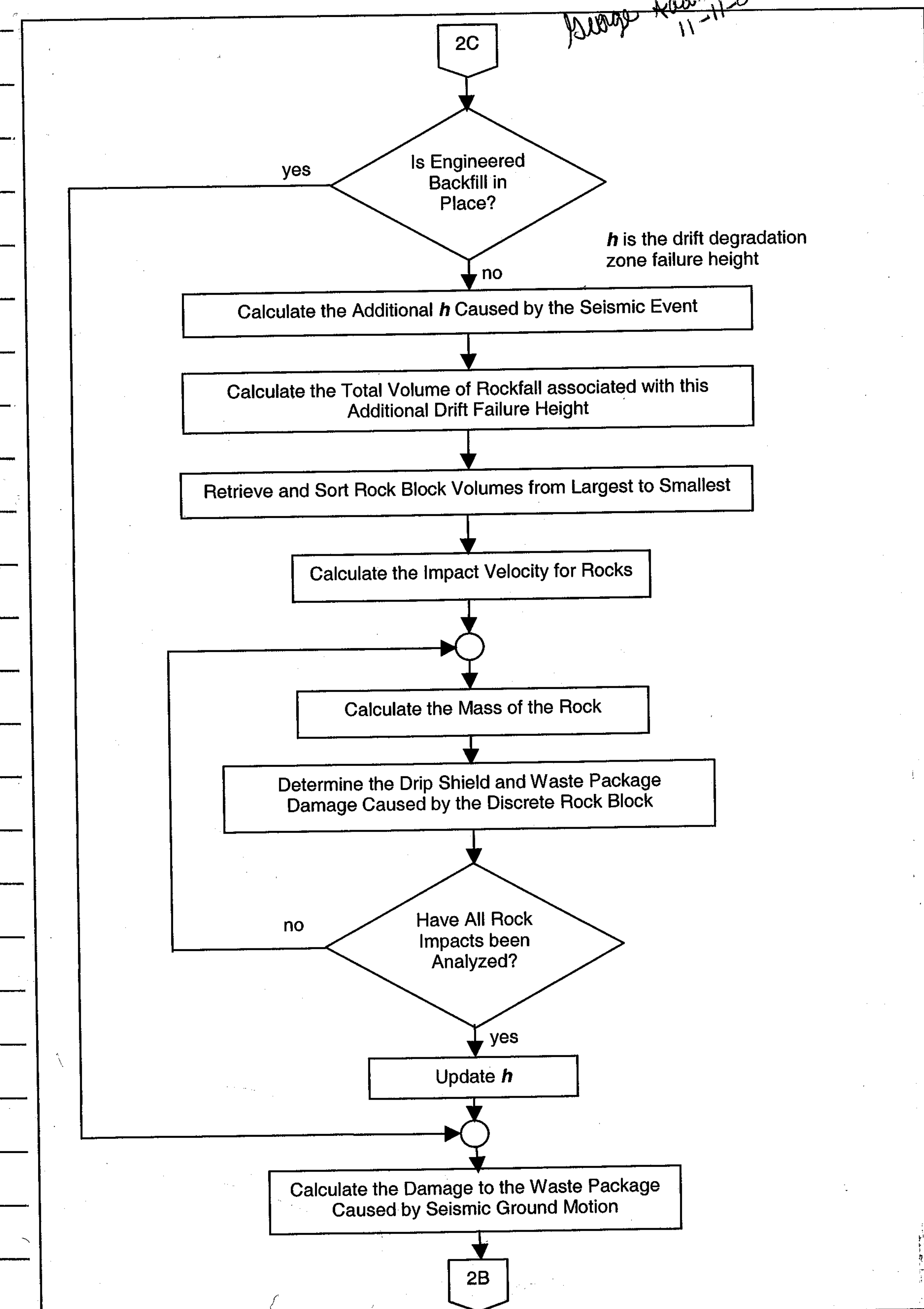
11-11-02 George Adams The flowchart below shows the calculation of damage due to static rockfall load during a seismic event.

George Adams 11-11-02



11-11-02 George Adams The flowchart below shows the calculation of damage to the drip shield and waste package caused by discrete rock impacts.

George Adams 11-11-02



11-11-02 George Adams

The following changes have been identified for code version 5.0 Beta:

1) Calculate the static rockfall load (tonnes/m) needed to initiate creep in the drip shield plate using the following equation:

$$L_{plate} = 1.781 + 0.721\, L_{buckling} - 0.003\, L_{buckling}^2$$

where L_{plate} is the static rockfall load (tonnes/m) needed to initiate creep in the drip shield plate.

2) Convert the static load acting on the drip shield in kg/m to tonnes/m by dividing by 1000 kg/tonne.

3) Compare the static load acting on the drip shield (F_s) to L_{plate}. If $F_s > L_{plate}$ then initiate creep in the drip shield plate.

11-12-02 George Adams

The following is a continuation of the changes identified for code version 5.0 Beta:

4) Calculate the static rockfall load (tonnes/m) needed to initiate creep in the drip shield bulkhead using the following equation:

$$L_{bulkhead} = 8.937 + 0.588\, L_{buckling} - 0.001\, L_{buckling}^2$$

where $L_{bulkhead}$ is the static rockfall load (tonnes/m) needed to initiate creep in the drip shield bulkhead, and $L_{buckling}$ is the drip shield buckling load (tonnes/m)

5) Compare the static load acting on the drip shield (F_s) to $L_{bulkhead}$. If $F_s > L_{bulkhead}$, then initiate creep in the drip shield bulkhead.

6) Drip shield buckling load (kg/m) is a beta distribution. Its parameters are changed to the following:

A = 25000, B = 150000, p = 2.08134, q = 8.92986

The updated distribution is shown on page 51.

■ Fs

mode and 80 percentile after normalization

```
In[77]:= xmax = 150000;
         xmin = 25000;
         xmode = 40000;
         x80 = 60000;

In[81]:= xmode = (xmode - xmin) / (xmax - xmin);
         x80 = (x80 - xmin) / (xmax - xmin);
         {xmode, x80}

Out[83]= {3/25, 7/25}
```

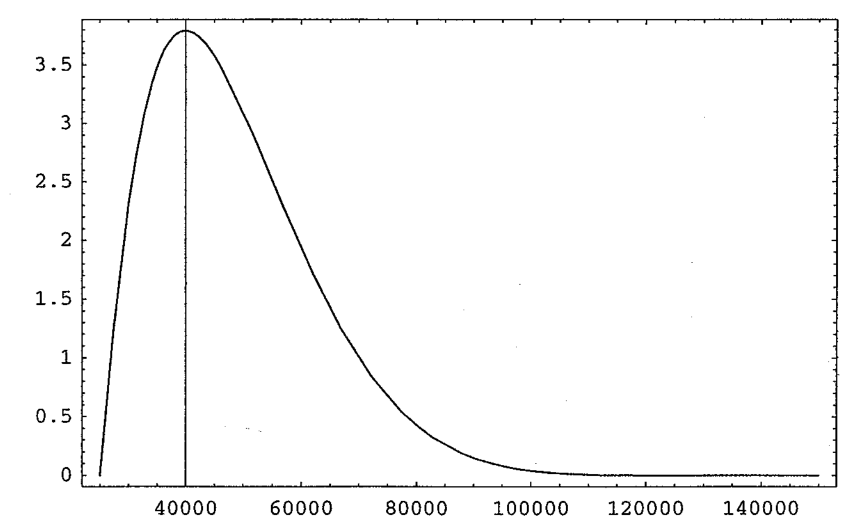
alpha parameter

George Adams 11-12-02

```
In[84]:= ahat =
           a /. FindRoot[BetaRegularized[x80, a, (-1 + a + 2 xmode - a xmode)/xmode] == 0.8, {a, 1.2}]

Out[84]= 2.08134
```

beta parameter

```
In[85]:= bhat = (-1 + ahat + 2 xmode - ahat xmode)/xmode

Out[85]= 8.92986

In[86]:= Plot[PDF[BetaDistribution[ahat, bhat], (x - xmin) / (xmax - xmin)],
           {x, xmin, xmax}, Frame -> True]
```




```
Out[86]= - Graphics -

In[95]:= values = Table[x, {x, xmin, xmax, (xmax - xmin) / 100.}];
         f[x_] := PDF[BetaDistribution[ahat, bhat], (x - xmin) / (xmax - xmin)];
         result = Transpose[{values, f[values]}];
         Export["D:\\fs.dat", result]

Out[98]= D:\fs.dat
```

11-12-02 George Adams

The following is a continuation of changes identified for code version 5.0 beta:

7) After dripshield buckling load (kg/m) is sampled divide the sampled value by 1000 kg/tonne to convert the sampled value to tonnes/m.

8) Replace references to threshold height in the code by impact mitigation height. This change affects the MECHFAIL module.

9) As part of seismic analysis, discrete rock blocks have an effect when the drift degradation zone failure height is less than or equal to the impact mitigation height. However, as part of discrete rock block impact analysis, the drift degradation zone failure height may become greater than the impact mitigation height. If this is the case, then discrete rock block impacts can only be analyzed up to the impact mitigation height. Above the impact mitigation height, the damage caused by the static rockfall load would have to be analyzed.

10) As shown on the flowchart of page 49, the calculation of additional drift degradation zone failure height will be moved to after the check for engineered backfill in place.

11) The abstraction for drip shield dynamic plate plastic strain and drip shield dynamic bulkhead plastic strain could generate negative plastic strains for low kinetic energy impacts. Therefore, if the plastic strain is less than ø, it will be set to ø.

George Adams 12-16-02

12-16-02 George Adams

The following is a continuation of changes identified for code version 5.0 beta:

12) Impact Mitigation Height corresponds to a one-half meter thickness of rockfall rubble above the drip shield crown. Make the one-half meter input to Impact Mitigation Height a parameter in TPA.INP.

13) Modify the equation used to calculate the static rockfall load (tonnes/m) needed to initiate creep in the drip shield plate. This equation was previously identified on page 50, #1. Modify the equation to the following:

$$L_{plate} = [4.903 \times 10^{0}] + [5.120 \times 10^{-1}]\, L_{buckling} - [1.130 \times 10^{-3}]\, L_{buckling}^{2}$$

where, L_{plate} is the static rockfall load (tonnes/m) needed to initiate creep in the drip shield plate and $L_{buckling}$ is the drip shield buckling load (tonnes/m).

14) Modify the comparison identified on page 50, #3. Instead of checking if $F_s > L_{plate}$, check if $F_s >= L_{plate}$. That is, check if F_s is greater than or equal to L_{plate}.

15) Modify the equation used to calculate the static rockfall load (tonnes/m) needed to initiate creep in the drip shield bulkhead. This equation was previously identified on page 50, #4. Modify the equation to the following:

$$L_{bulkhead} = [1.277 \times 10^{1}] + [3.572 \times 10^{-1}]\, L_{buckling} + [2.703 \times 10^{-4}]\, L_{buckling}^{2}$$

where, $L_{bulkhead}$ is the static rockfall load (tonnes/m) needed to initiate creep in the drip shield bulkhead and $L_{buckling}$ is the drip shield buckling load (tonnes/m).

16) Modify the comparison identified on page 50, #5. Instead of checking if $F_s > L_{bulkhead}$, check if $F_s >= L_{bulkhead}$. That is, check if F_s is greater than or equal to $L_{bulkhead}$.

12-16-02 Doug Adams

The following is a continuation of changes identified for code version 5.0 beta:

17) Convert the rock block mass from Kg to tonnes by dividing by 1000 Kg/tonne.

18) Update the drip shield dynamic displacement using the following:

$$\text{Drip shield dynamic displacement} = [7.720 \times 10^{-3}]M + [3.402 \times 10^{-3}]M^2 - [3.544 \times 10^{-4}]M^3 + [1.041 \times 10^{-4}]Mv_{rock} + [1.443 \times 10^{-3}]Mv_{rock}^2$$

where, M is the rock block mass in tonnes/m and v_{rock} is the rock block impact velocity in m/s.

19) Update the drip shield dynamic plate plastic strain using the following equation:

$$\text{Drip shield dynamic plate plastic strain} = -[5.229 \times 10^{-2}] - [8.765 \times 10^{-3}]M + [1.338 \times 10^{-2}]Mv_{rock} + [1.156 \times 10^{-4}]Mv_{rock}^2$$

where, M is the rock block mass in tonnes/m and v_{rock} is the rock block impact velocity in m/s.

20) Update the drip shield dynamic bulkhead plastic strain using the following equation:

$$\text{Drip shield dynamic bulkhead plastic strain} = -[7.877 \times 10^{-3}] + [1.195 \times 10^{-3}]M + [2.447 \times 10^{-3}]Mv_{rock} + [2.766 \times 10^{-4}]Mv_{rock}^2$$

where, M is the rock block mass in tonnes/m and v_{rock} is the rock block impact velocity in m/s

21) Modify the calculation of the drift degradation rate to account for the initial drift failure height. The drift failure height is initially set to the drift radius. Therefore, the drift degradation rate is calculated as follows:

$$\text{drift degradation rate} = (H_{max} - \text{drift radius}) / \text{drift degradation time}$$

where, H_{max} is the maximum drift failure height

22) There is the possibility that the corrosion failure of the drip shield will preceed failures due to mechanical means. If corrosion failure occurs and there are still drip shields that have not failed, then print a warning message that corrosion failure occurred prior to failure from mechanical means. The reason this is important is that mechanical failure does not account for the drop in thickness of the drip shield until the drip shield has completely failed.

23) Add descriptive header text to the seisbs1.dis and seisbs2.dis files. These files contain the rock block size distributions for rock block types 1 and 2, respectively.

24) Create a default parameter file (mechfail.def) from a mean case tpa run.

25) Modify the mechfail.def file to associate parameter names with those in tpa.inp.

26) Create a test case for the mechanical failure model to verify that a study over 10,000 years will produce the same or similar results to a study performed over 100,000 years.

27) Modify the seismic hazard curve as follows:

SeismicHazardCurveforSEISMO

1Ø

0.050	142.0
0.100	409.0
0.169	1000.0
0.350	3968.0
0.534	10000.0
0.750	22340.0
1.305	100000.0
2.000	336261.0
3.000	1158062.0
6.000	1000000000.0

12-16-02 George Adams

The following is a continuation of changes identified for code version 5.0beta:

28) Modify the rock type percentages for each subarea as follows:

constant

FractionRockTypeOneInSubarea_{1..10}[]

0.75

29) Modify the distribution for drift degradation time to set the lower bound to 250 years. The new distribution is as follows:

beta

DegradationTimeRockTypeOne{Two}GridElement_{1..10} [yr]

250.0 1000.0 3.25842 1.82124

30) Modify the bulking factor for rock types one and two as follows:

uniform

BulkingFactorRockTypeOneGridElement_{1..10}

1.15 1.50

- and -

uniform

BulkingFactorRockTypeTwoGridElement_{1..10}

1.35 1.50

31) Modify the drip shield buckling load as follows:

beta

DripShieldBucklingLoadGridElement_{1..10} [Kg/m]

25000 150000 2.08134 8.92986

32) Invoke the mechanical failure code (SEISMO/MECHFAIL) on a subarea basis instead of a repository basis.

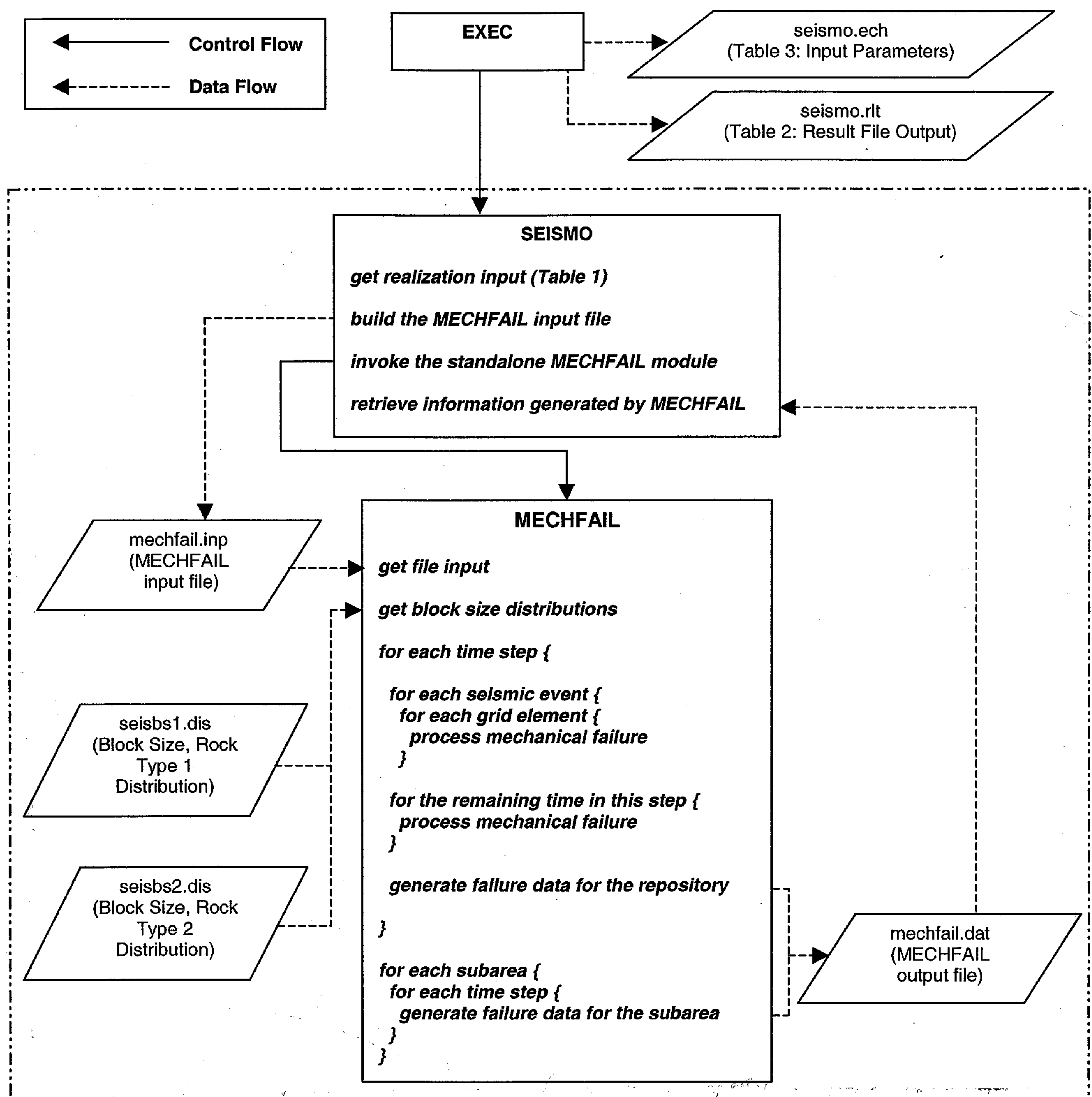
George Adams 12-16-02

12-16-02 George Adams

The flowchart on page 40 was updated to show the control and data flows.

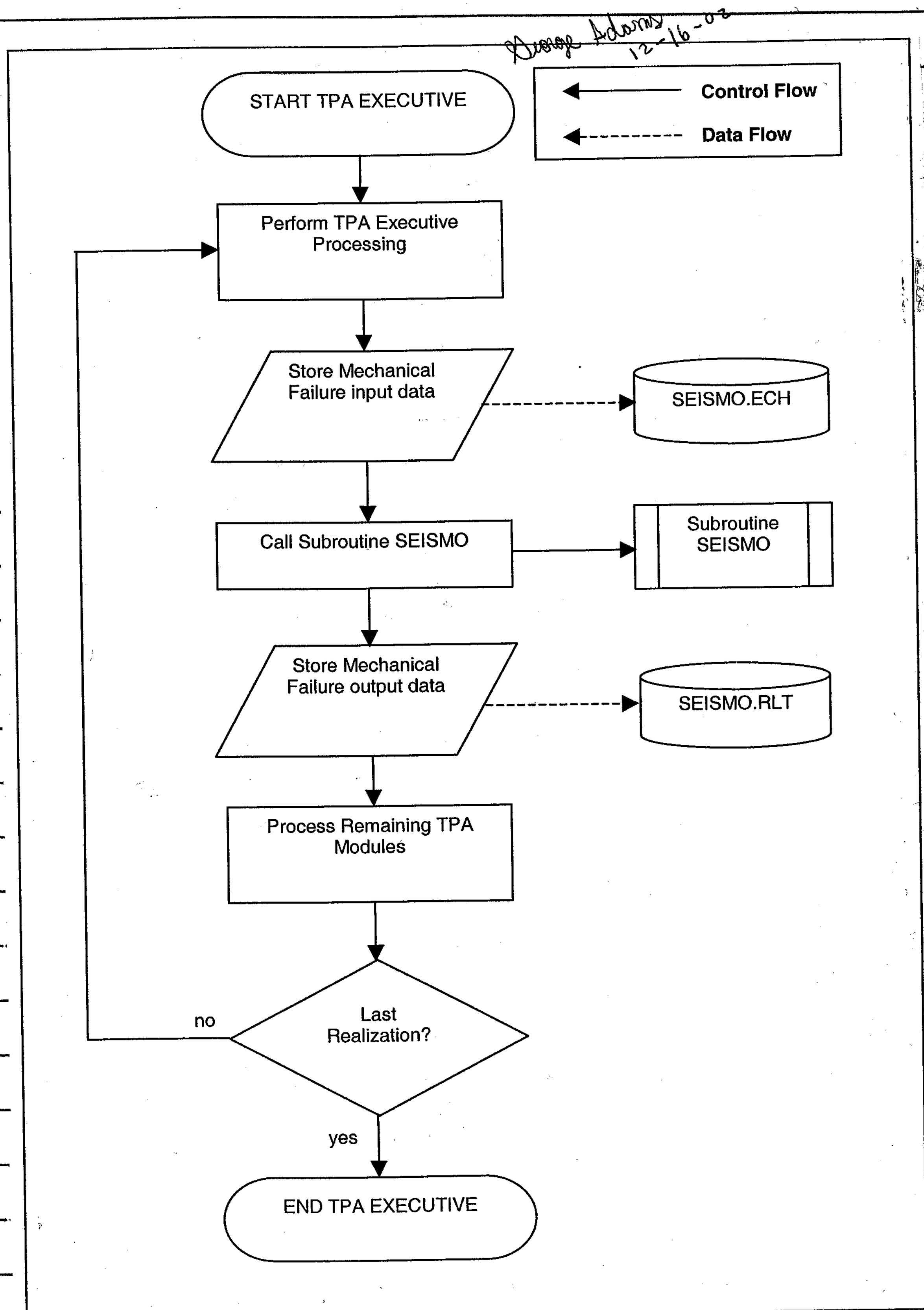
George Adams 12-16-02

Flowchart and Data Flow Diagram



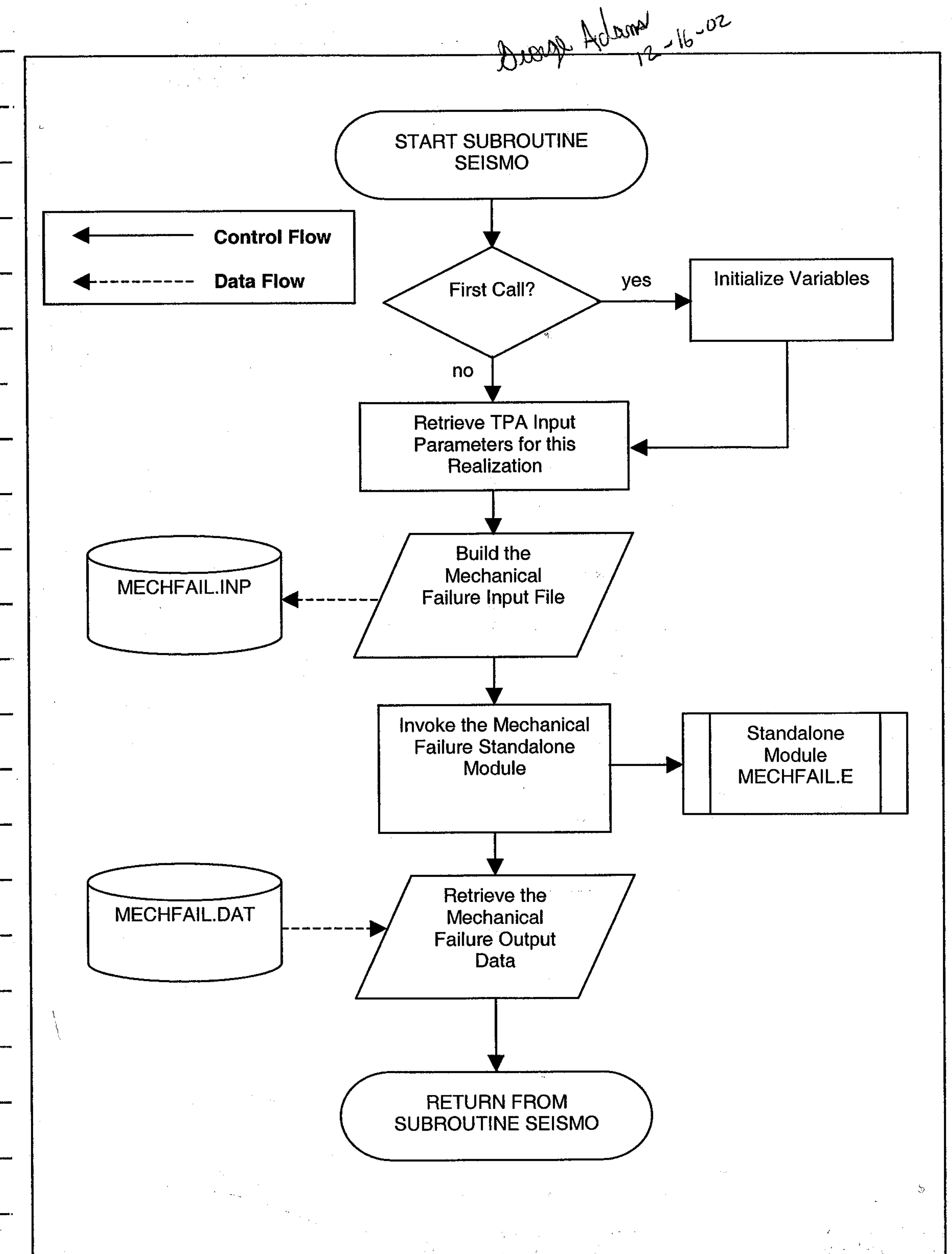
12-16-02 George Adams

The flowchart on page 41 was updated to show the control and data flows.



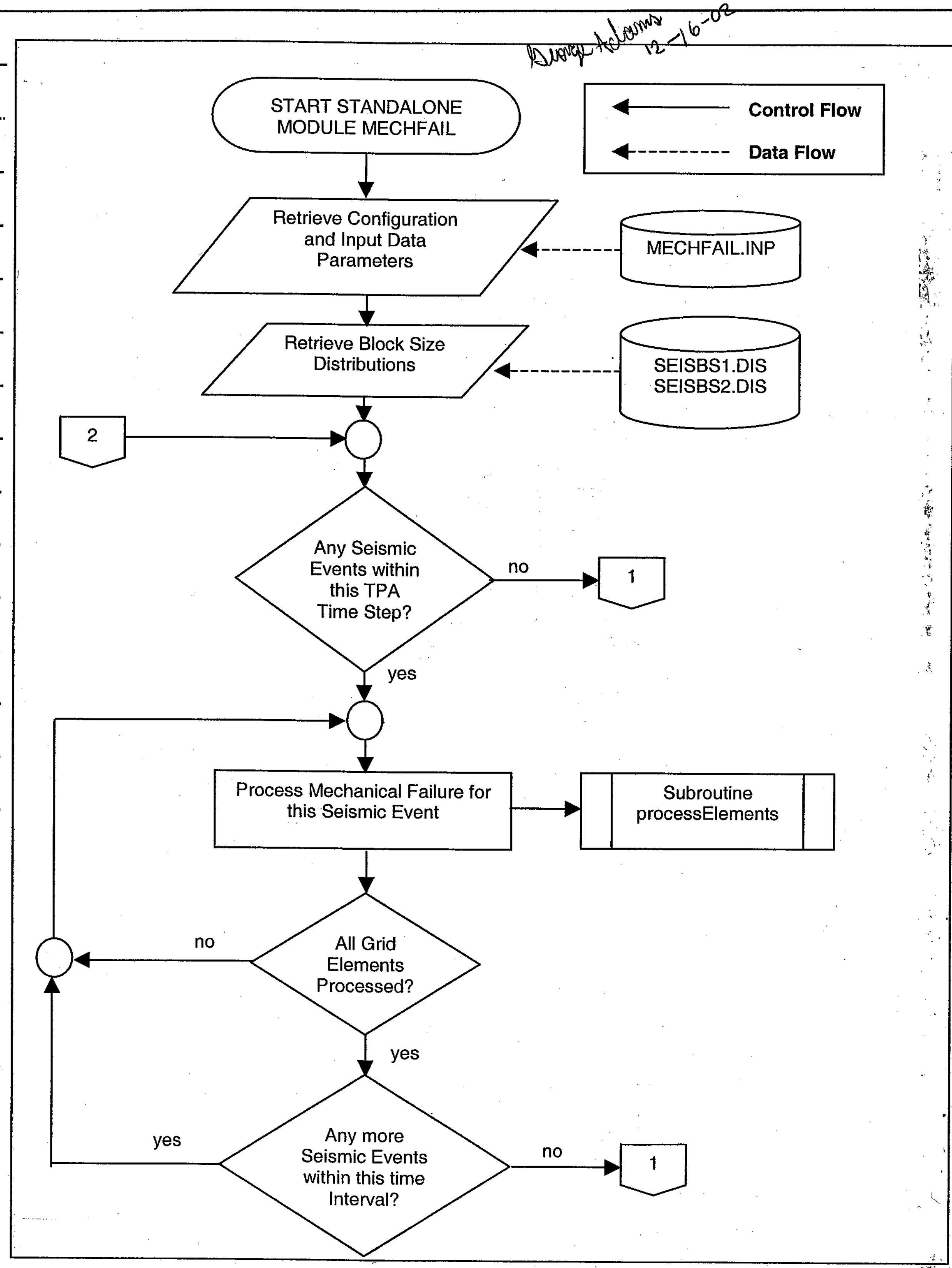
12-16-02 George Adams

The flowchart on page 42 was updated to show the control and data flows.



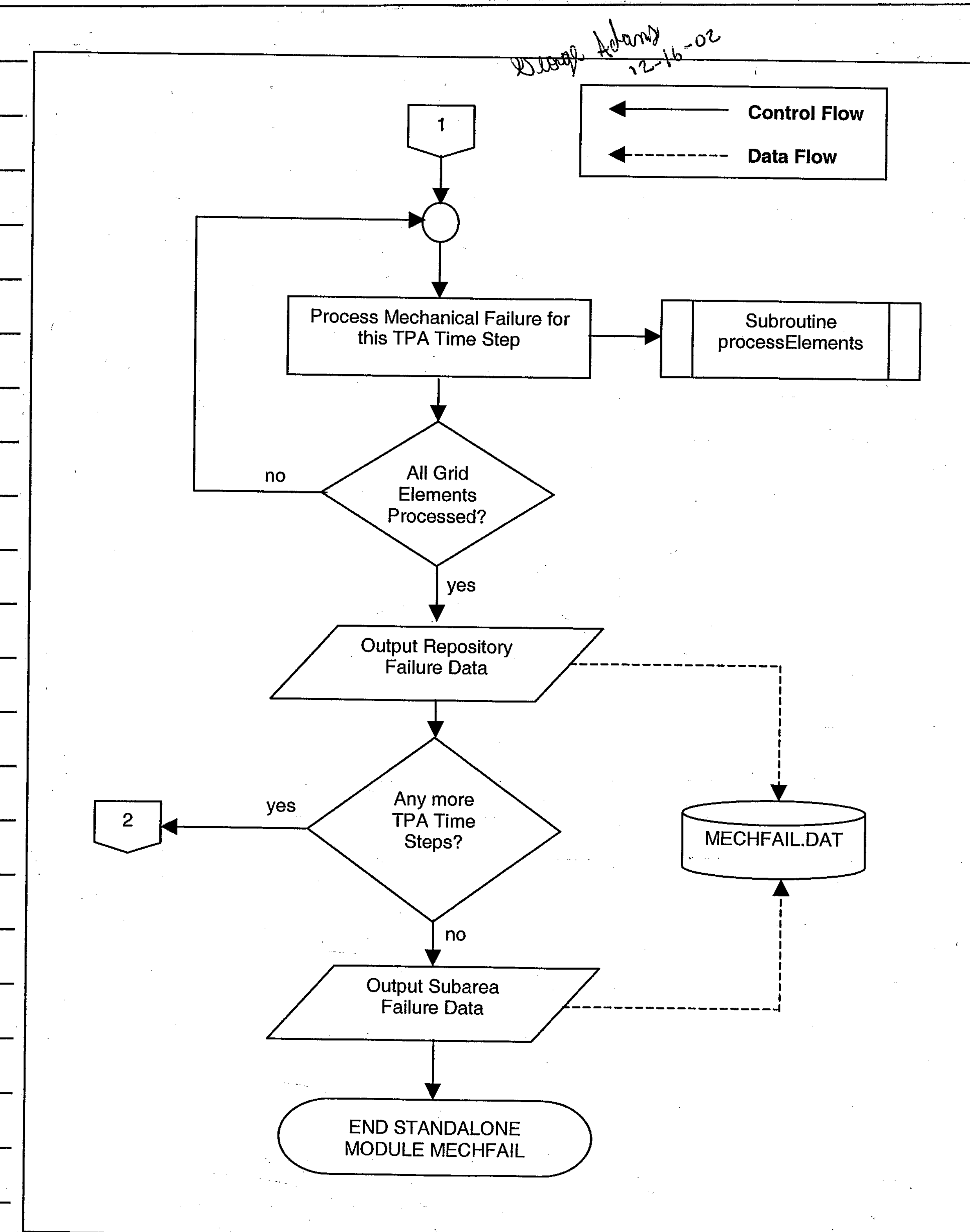
12-16-02 George Adams

The flowchart on page 43 was updated to show the control and data flows.



12-16-02 George Adams

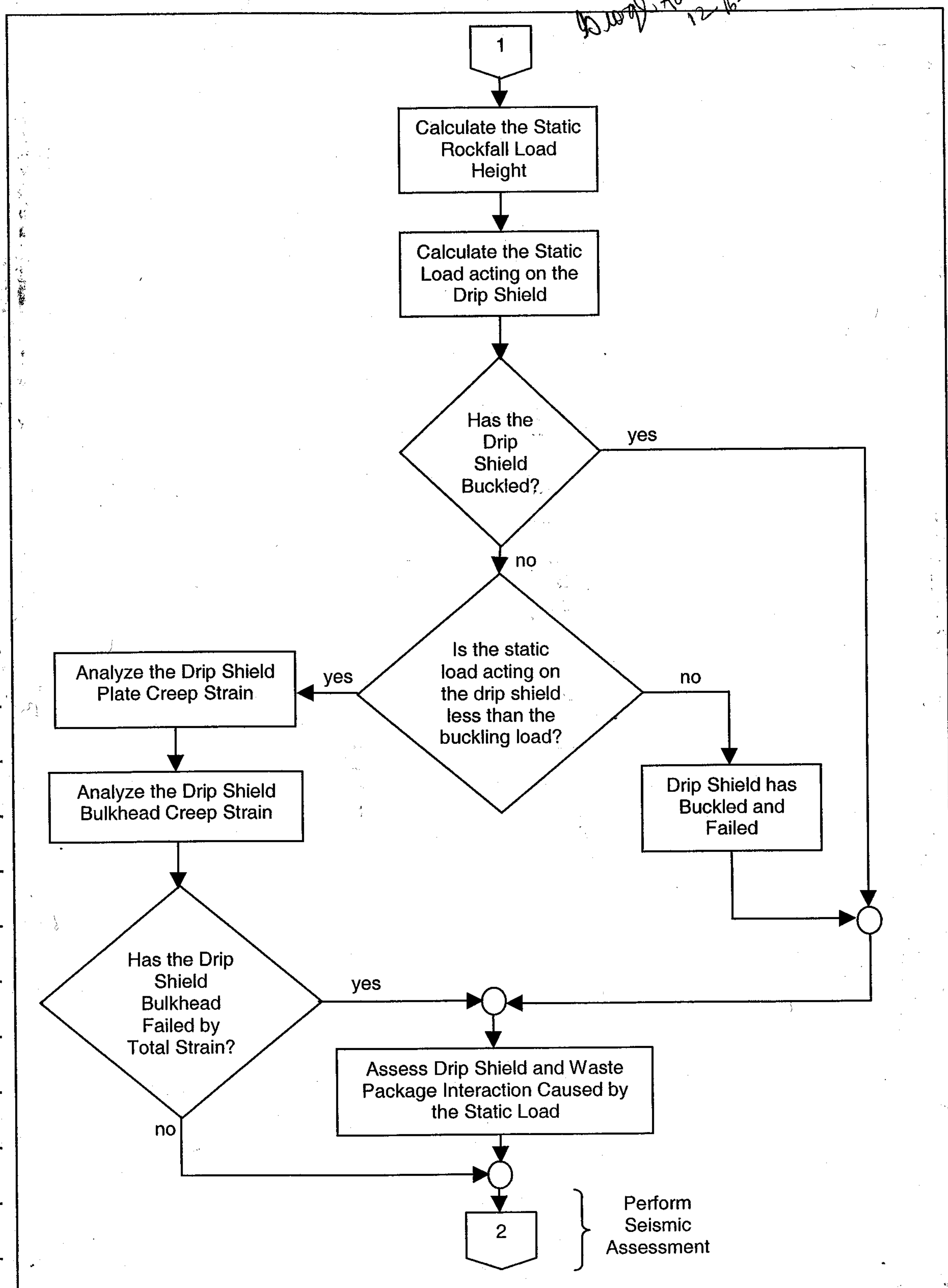
The flowchart on page 44 was updated to show the control and data flows



12-16-02 Doug Adams

The creep failure portions of the flowchart on page 46 were updated.

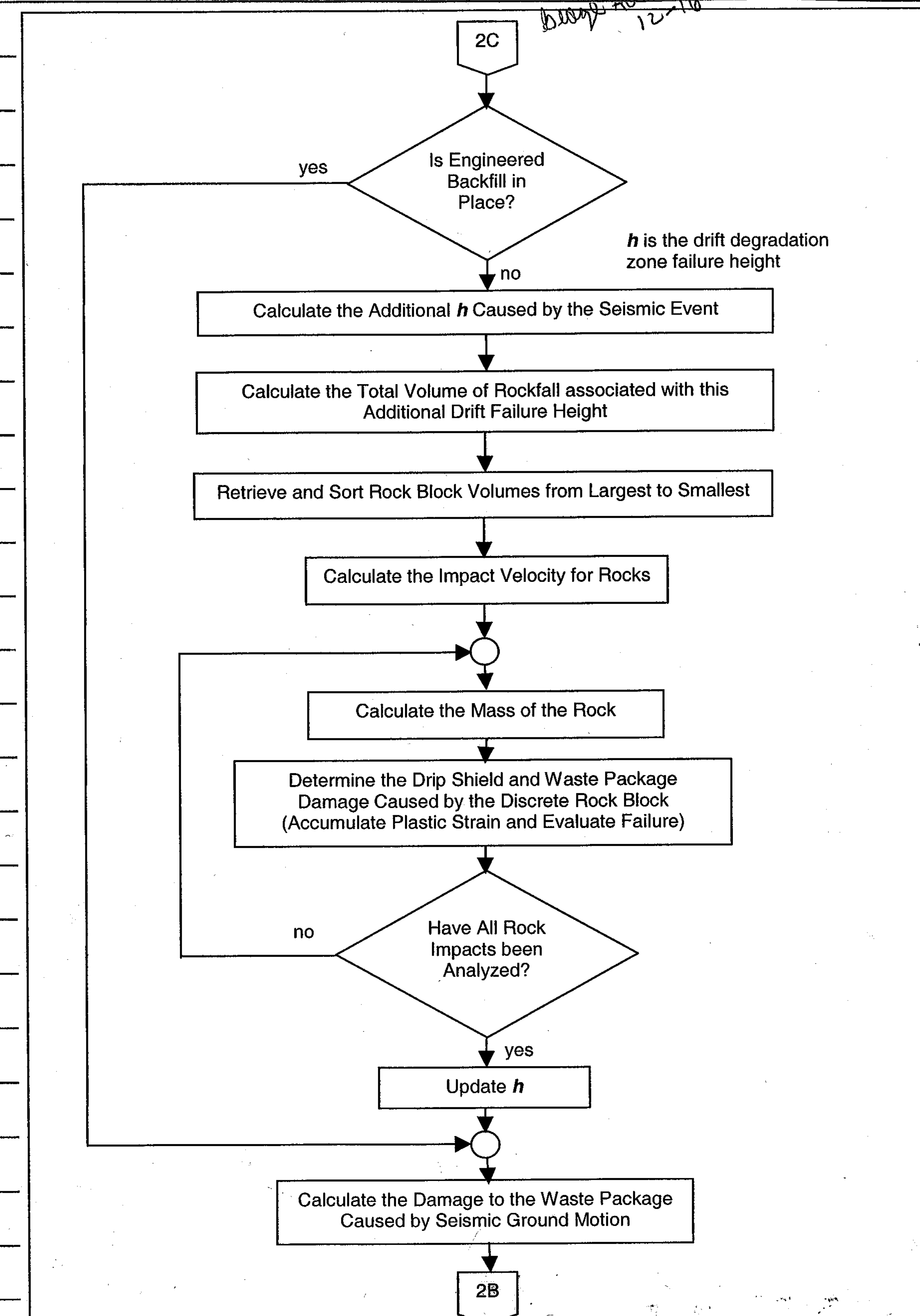
Doug Adams 12-16-02



12-16-02 Doug Adams

The flowchart on page 49 was updated to indicate that plastic strain is accumulated.

Doug Adams 12-16-02

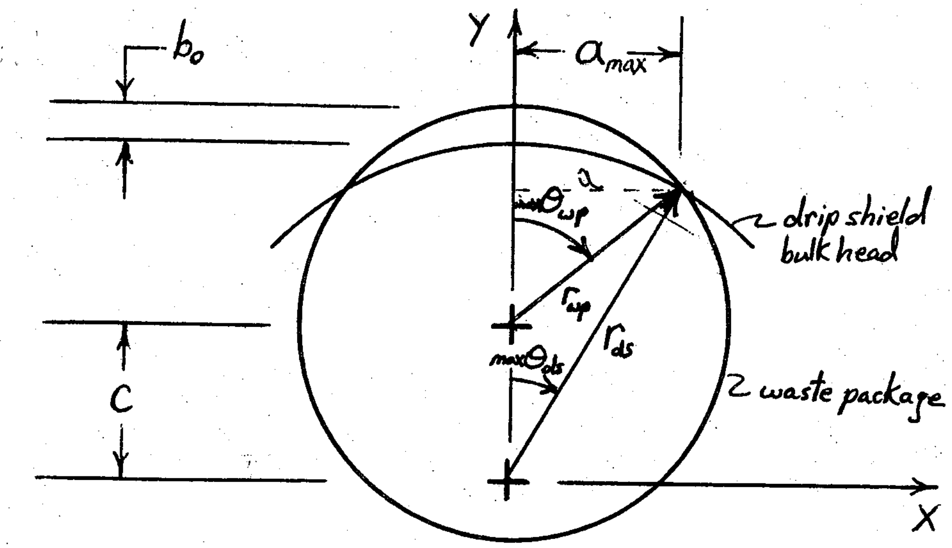


12-16-02 George Adams

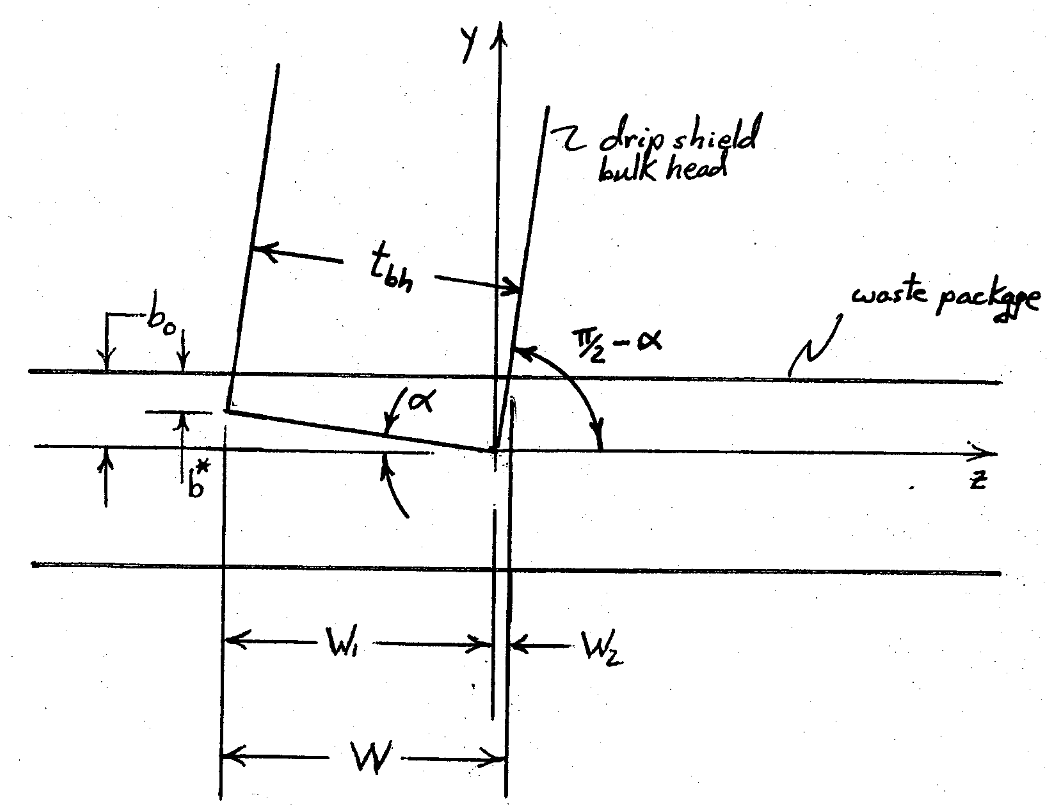
Changes to the mechanical failure code to include SEISMO / MECHFAIL modules was incorporated into Software Change Report (SCR) number PA-SCR-414.

George Adams 12-16-02

2-11-04 George Adams Within TPA version 5.0r, evaluated waste package failure due to contact with the drip shield bulkhead. The following model was incorporated into the MECHFAIL module.



George Adams 2-11-04



Assuming negligible friction exists between the drip shield bulk head and waste package outer barrier, the contact area that can be used to calculate the average stress generated between these two components can be approximated as

$$A = 2\int_0^{a_{max}} W(x)\,dx$$

↳ area - contact

2-11-04 George Adams

The following equations were incorporated into the MECHFAIL module:

$$\max \theta_{ds} = \cos^{-1}\left(1 + \frac{2 b_0 r_{wp} - b_0^2}{2 r_{ds} r_{wp} - 2 b_0 r_{ds} - 2 r_{ds}^2}\right)$$

$$b^* = b_0 - t_{bh} \sin(\alpha)$$

$$\max \theta_{ds}^* = \cos^{-1}\left(1 + \frac{2 b^* r_{wp} - b^{*2}}{2 r_{ds} r_{wp} - 2 b^* r_{ds} - 2 r_{ds}^2}\right)$$

For the case where $\alpha > \sin^{-1}\left(\frac{b_0}{t_{bh}}\right)$, $X_1 = \phi$ and $X_2 = \max \theta_{ds}$

$$A = [4 r_{ds} / \sin(2\alpha)] (b_0 - r_{wp} + r_{ds}) (\sin(X_2)) - [4 r_{ds}^2 / \sin(2\alpha)] \left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2}\right] + [4 r_{ds} r_{wp} / \sin(2\alpha)] \left\{ \frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}} \sin(X_2)\right]\right\}$$

For the case where $0 < \alpha \le \sin^{-1}\left(\frac{b_0}{t_{bh}}\right)$, $X_1 = 0$, $X_2 = \max \theta_{ds}^*$ and $X_3 = \max \theta_{ds}$

$$A = 2 t_{bh} \cos(\alpha) \sin(X_2) + 2(b_0 - r_{wp} + r_{ds}) \tan\alpha \sin(X_2) - 2 r_{ds} \tan(\alpha) \left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2}\right] +$$

$$2 r_{wp} \tan(\alpha) \left\{\frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right]\right\} +$$

$$\frac{4 r_{ds}}{\sin(2\alpha)} (b_0 - r_{wp} + r_{ds}) [\sin(X_3) - \sin(X_2)] -$$

$$\frac{4 r_{ds}^2}{\sin(2\alpha)} \left[\frac{1}{2}\sin(X_3)\cos(X_3) + \frac{X_3}{2} - \frac{1}{2}\sin(X_2)\cos(X_2) - \frac{X_2}{2}\right] +$$

2-11-04 George Adams

The following is a continuation of the equations from page 66:

$$\frac{4 r_{ds} r_{wp}}{\sin(2\alpha)} \left\{ \frac{\sin(X_3)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_3)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_3)\right] - \frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} - \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right]\right\}$$

For the case where $\alpha = 0$, $X_1 = 0$, $X_2 = X_3 = \max \theta_{ds}$

$$A = 2 t_{bh} \cos(\alpha) \sin(X_2) + 2(b_0 - r_{wp} + r_{ds}) \tan(\alpha) \sin(X_2) - 2 r_{ds} \tan(\alpha) \left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2}\right] +$$

$$2 r_{wp} \tan(\alpha) \left\{\frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right]\right\}$$

Calculate the maximum shearing stress for the waste package as follows:

$$\text{waste package maximum shearing stress} = \frac{\text{static load on the drip shield}}{\text{contact area } (A)}$$

The maximum shearing stress is compared to 90% of the ultimate tensile strength to determine if waste package failure occurred.

The ultimate tensile strength is computed as follows:
For the waste package, the UTS = 98500 psi. This value is converted to MPa by multiplying by 6.894757 e-3 giving an ultimate tensile strength of 679.1336 MPa. Ninety percent of this value is 611.2202 MPa.

5-26-04 ~~2-26-04~~ George Adams

A detailed derivation for the information contained on pages 65, 66, and 67 is included on the following pages. (Page 1 of the detailed derivation is shown on page 65.)

George Adams 5-26-04

2/

Calculate a_{max}:

$$r_{ds}\cos({}_{max}\theta_{ds}) = c + r_{wp}\cos({}_{max}\theta_{wp}) \quad (1)$$

projection_length

$$r_{ds}\sin({}_{max}\theta_{ds}) = r_{wp}\sin({}_{max}\theta_{wp}) \quad ; \quad = a_{max} \quad (2)$$

$$b_o + r_{ds} = c + r_{wp} \quad (3)$$

Given 3 eq'ns (1-3) and 3 unknowns (c, ${}_{max}\theta_{ds}$, ${}_{max}\theta_{wp}$), a_{max} can be approximated. Specifically, solve eq'n (3) for c and substitute into eq'n (1).

$$c = b_o + r_{ds} - r_{wp} \quad (4)$$

Substituting eq'n (4) into eq'n (1) gives

$$r_{ds}\cos({}_{max}\theta_{ds}) = b_o + r_{ds} - r_{wp} + r_{wp}\cos({}_{max}\theta_{wp}) \quad (5)$$

Now, solve eq'n (5) for ${}_{max}\theta_{wp}$ and substitute the result into eq'n (2).

$${}_{max}\theta_{wp} = \cos^{-1}\left\{\frac{1}{r_{wp}}\left[r_{wp} - r_{ds} - b_o + r_{ds}\cos({}_{max}\theta_{ds})\right]\right\} \quad (6)$$

Substituting eq'n (6) into eq'n (2) gives

$$r_{ds}\sin({}_{max}\theta_{ds}) = r_{wp}\sin\left(\cos^{-1}\left\{\frac{1}{r_{wp}}\left[r_{wp} - r_{ds} - b_o + r_{ds}\cos({}_{max}\theta_{ds})\right]\right\}\right)$$

Because

$$\sin[\cos^{-1}(x)] = (1 - x^2)^{1/2}$$

Then

$$r_{ds}\sin({}_{max}\theta_{ds}) = r_{wp}\left\{1 - \left[\frac{r_{wp} - r_{ds} - b_o + r_{ds}\cos({}_{max}\theta_{ds})}{r_{wp}}\right]^2\right\}^{1/2}$$

$$= \left\{r_{wp}^2 - \left[r_{wp} - r_{ds} - b_o + r_{ds}\cos({}_{max}\theta_{ds})\right]^2\right\}^{1/2}$$

$$r_{ds}^2\sin^2({}_{max}\theta_{ds}) = r_{wp}^2 - r_{wp}^2 + 2r_{ds}r_{wp} - r_{ds}^2 + 2b_o r_{wp} - 2b_o r_{ds} - 2r_{ds}r_{wp}\cos({}_{max}\theta_{ds}) + 2r_{ds}^2\cos({}_{max}\theta_{ds}) - b_o^2 + 2b_o r_{ds}\cos({}_{max}\theta_{ds}) - r_{ds}^2\cos^2({}_{max}\theta_{ds})$$

$$2r_{ds}^2 = 2r_{ds}r_{wp} + 2b_o r_{wp} - 2b_o r_{ds} - 2r_{ds}r_{wp}\cos({}_{max}\theta_{ds}) + 2r_{ds}^2\cos({}_{max}\theta_{ds}) - b_o^2 + 2b_o r_{ds}\cos({}_{max}\theta_{ds})$$

5-26-04 George Adams

Detailed derivation continued.

George Adams 5-26-04

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$$\therefore \quad {}_{max}\theta_{ds} = \cos^{-1}\left(\frac{2r_{ds}r_{wp} + 2b_o r_{wp} - 2b_o r_{ds} - b_o^2 - 2r_{ds}^2}{2r_{ds}r_{wp} - 2b_o r_{ds} - 2r_{ds}^2}\right) \quad (7a)$$

or

$$\therefore \quad {}_{max}\theta_{ds} = \cos^{-1}\left(1 + \frac{2b_o r_{wp} - b_o^2}{2r_{ds}r_{wp} - 2b_o r_{ds} - 2r_{ds}^2}\right) \quad (7b)$$

theta_ds_max

From eq'n (2),

$$a_{max} = r_{ds}\sin\left[\cos^{-1}\left(1 + \frac{2b_o r_{wp} - b_o^2}{2r_{ds}r_{wp} - 2b_o r_{ds} - 2r_{ds}^2}\right)\right]$$

$$= r_{ds}\left\{1 - \left[1 + \frac{2b_o r_{wp} - b_o^2}{2r_{ds}r_{wp} - 2b_o r_{ds} - 2r_{ds}^2}\right]^2\right\}^{1/2}$$

$$= r_{ds}\left\{1 - \left[1 + \frac{2b_o r_{wp} - b_o^2}{r_{ds}r_{wp} - b_o r_{ds} - r_{ds}^2} + \left(\frac{2b_o r_{wp} - b_o^2}{2r_{ds}r_{wp} - 2b_o r_{ds} - 2r_{ds}^2}\right)^2\right]\right\}^{1/2}$$

$$= r_{ds}\left[-\frac{2b_o r_{wp} - b_o^2}{r_{ds}r_{wp} - b_o r_{ds} - r_{ds}^2} - \frac{1}{4}\left(\frac{2b_o r_{wp} - b_o^2}{r_{ds}r_{wp} - b_o r_{ds} - r_{ds}^2}\right)^2\right]^{1/2} \quad (8)$$

The next task is to establish/formulate the W(x) function. When developing W(x) it is important to recognize that it will be discontinuous if

$$\alpha < \sin^{-1}\left(\frac{b_o}{t_{bh}}\right)$$

For the case where $\alpha \geq \sin^{-1}\left(\frac{b_o}{t_{bh}}\right)$

$$\tan(\alpha) = \frac{b(x)}{W_1} \quad (9)$$

$$\tan\left(\frac{\pi}{2} - \alpha\right) = \frac{b(x)}{W_2} \quad (10)$$

$$W = W_1 + W_2 \quad (11)$$

Solving eq'ns (9) and (10) for W_1 & W_2, respectively, and substituting into eq'n (11) gives

$$W = \frac{b}{\tan(\alpha)} + \frac{b}{\tan\left(\frac{\pi}{2} - \alpha\right)}$$

$$= \frac{b}{\tan(\alpha)} + \frac{b}{\cot(\alpha)}$$

$$= \frac{b}{\sin(\alpha)\cos(\alpha)} \quad (12a)$$

$$= \frac{2b}{\sin(2\alpha)} \quad (12b)$$

5-26-04 George Adams

Detailed derivation continued

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To complete the function for $W(x)$ we need to formulate $b(x)$, i.e., equivalently, $b(\theta_{ds})$.

$$b = C + r_{wp}\cos(\theta_{wp}) - r_{ds}\cos(\theta_{ds}) \qquad (13)$$

$$r_{ds}\sin(\theta_{ds}) = r_{wp}\sin(\theta_{wp}) \qquad (14)$$

Solving eq'n (14) for θ_{wp} and substituting into eq'n (13)

$$b = C + r_{wp}\cos\left\{\sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(\theta_{ds})\right]\right\} - r_{ds}\cos(\theta_{ds}) \qquad (15)$$

Now, substitute eq'n (4) into eq'n (15),

$$b = b_o + r_{ds} - r_{wp} + r_{wp}\left\{1 - \left[\frac{r_{ds}}{r_{wp}}\sin(\theta_{ds})\right]^2\right\}^{1/2} - r_{ds}\cos(\theta_{ds})$$

$$\therefore \quad b = b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2} \qquad (16)$$

Finally, substitute eq'n (16) into eq'n (12b)

$$\therefore \quad W = \frac{2}{\sin(2\alpha)}\{b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2}\} \qquad (17)$$

Recasting the contact area in terms of θ_{ds},

$$A = 2\int_0^{\max\theta_{ds}} W(\theta_{ds})\, r_{ds}\cos(\theta_{ds})\, d\theta_{ds} \qquad (18)$$

$$= \frac{4r_{ds}}{\sin(2\alpha)}\int_0^{\max\theta_{ds}} \{b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2}\}\cos(\theta_{ds})\,d\theta_{ds}$$

$$= \frac{4r_{ds}}{\sin(2\alpha)}\left\{\int_0^{\max\theta_{ds}}(b_o - r_{wp} + r_{ds})\cos(\theta_{ds})\,d\theta_{ds} - \int_0^{\max\theta_{ds}} r_{ds}\cos^2(\theta_{ds})\,d\theta_{ds} + \int_0^{\max\theta_{ds}}[r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2}\cos(\theta_{ds})\,d\theta_{ds}\right\}$$

$$\int_{X_1}^{X_2}\cos(\theta_{ds})\,d\theta_{ds} = \sin(\theta_{ds})\Big|_{X_1}^{X_2} = \sin(X_2) - \sin(X_1)$$

$$\int_{X_1}^{X_2}\cos^2(\theta_{ds})\,d\theta_{ds} = \frac{1}{2}\sin(\theta_{ds})\cos(\theta_{ds}) + \frac{\theta_{ds}}{2}\Big|_{X_1}^{X_2} = \frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2} - \frac{1}{2}\sin(X_1)\cos(X_1) - \frac{X_1}{2}$$

5-26-04 George Adams

Detailed derivation continued

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$$\int_{X_1}^{X_2}[1 - r'^2\sin^2(\theta_{ds})]^{1/2}\cos(\theta_{ds})\,d\theta_{ds} = \frac{\sin(\theta_{ds})}{2}[1 - r'^2\sin^2(\theta_{ds})]^{1/2} + \frac{1}{2r'}\sin^{-1}[r'\sin(\theta_{ds})]\Big|_{X_1}^{X_2}$$

$$= \frac{\sin(X_2)}{2}[1 - r'^2\sin^2(X_2)]^{1/2} + \frac{1}{2r'}\sin^{-1}[r'\sin(X_2)] - \frac{\sin(X_1)}{2}[1 - r'^2\sin^2(X_1)]^{1/2} - \frac{1}{2r'}\sin^{-1}[r'\sin(X_1)]$$

Plot as a function of α

$$\therefore \quad A = \frac{4r_{ds}}{\sin(2\alpha)}(b_o - r_{wp} + r_{ds})[\sin(X_2) - \sin(X_1)]$$
$$- \frac{4r_{ds}^2}{\sin(2\alpha)}\left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2} - \frac{1}{2}\sin(X_1)\cos(X_1) - \frac{X_1}{2}\right]$$
$$+ \frac{4r_{ds}r_{wp}}{\sin(2\alpha)}\left\{\frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2r_{ds}}\sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right] - \frac{\sin(X_1)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_1)\right]^{1/2} - \frac{r_{wp}}{2r_{ds}}\sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_1)\right]\right\}$$

where

$X_1 = 0$ and $X_2 = \max\theta_{ds}$; $\alpha \geq \sin^{-1}\left(\frac{b_o}{t_{bh}}\right)$

X_one x_two alpha

For the case where $\alpha < \sin^{-1}\left(\frac{b_o}{t_{bh}}\right)$

$$A = 2\int_0^{\max\theta_{ds}^*}\{t_{bh}\cos(\alpha) + (b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2})\tan(\alpha)\}\cos(\theta_{ds})\,d\theta_{ds}$$
$$+ 2\int_{\max\theta_{ds}^*}^{\max\theta_{ds}}\frac{2r_{ds}}{\sin(2\alpha)}\{b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2}\}\cos(\theta_{ds})\,d\theta_{ds}$$

From eq'n (7b),

theta_analysis_dsunew

$$\therefore \quad \max\theta_{ds}^* = \cos^{-1}\left(1 + \frac{2b^*r_{wp} - b^{*2}}{2r_{ds}r_{wp} - 2b^*r_{ds} - 2r_{ds}^2}\right)$$

where

$$\therefore \quad b^* = b_o - t_{bh}\sin(\alpha)$$

depth_analysis

$$2\int_0^{\max\theta_{ds}^*}\{t_{bh}\cos(\alpha) + (b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2})\tan(\alpha)\}\cos(\theta_{ds})\,d\theta_{ds}$$
$$= 2\int_0^{\max\theta_{ds}^*} t_{bh}\cos(\alpha)\cos(\theta_{ds})\,d\theta_{ds} + 2\int_0^{\max\theta_{ds}^*}\{b_o - r_{wp} + r_{ds}[1-\cos(\theta_{ds})] + [r_{wp}^2 - r_{ds}^2\sin^2(\theta_{ds})]^{1/2}\}\tan(\alpha)\cos(\theta_{ds})\,d\theta_{ds}$$

5-26-04 George Adams

Detailed derivation continued

George Adams 5-26-04 [redacted] 6/

$$= 2 t_{bh} \cos(\alpha) \int_0^{{}_{max}\theta_{ds}^*} \cos(\theta_{ds})\, d\theta_{ds}$$
$$+ 2(b_o - r_{wp} + r_{ds}) \tan(\alpha) \int_0^{{}_{max}\theta_{ds}^*} \cos(\theta_{ds})\, d\theta_{ds}$$
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$$- 2 r_{ds} \tan(\alpha) \int_0^{{}_{max}\theta_{ds}^*} \cos^2(\theta_{ds})\, d\theta_{ds}$$
$$+ 2 r_{wp} \tan(\alpha) \int_0^{{}_{max}\theta_{ds}^*} \left[1 - \frac{r_{ds}^2}{r_{wp}^2} \sin^2(\theta_{ds})\right]^{1/2} \cos(\theta_{ds})\, d\theta_{ds}$$

$$= 2 t_{bh} \cos(\alpha) [\sin(X_2) - \sin(X_1)]$$
$$+ 2(b_o - r_{wp} + r_{ds}) \tan(\alpha) [\sin(X_2) - \sin(X_1)]$$
$$- 2 r_{ds} \tan(\alpha) \left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2} - \frac{1}{2}\sin(X_1)\cos(X_1) - \frac{X_1}{2}\right]$$
$$+ 2 r_{wp} \tan(\alpha) \left\{ \frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right] - \frac{\sin(X_1)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_1)\right]^{1/2} - \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_1)\right] \right\}$$

Plot as a function of α

$$\therefore A = 2 t_{bh} \cos(\alpha) [\sin(X_2) - \cancel{\sin(X_1)}]^{\to 0}$$
$$+ 2(b_o - r_{wp} + r_{ds}) \tan(\alpha) [\sin(X_2) - \cancel{\sin(X_1)}]^{\to 0}$$
$$- 2 r_{ds} \tan(\alpha) \left[\frac{1}{2}\sin(X_2)\cos(X_2) + \frac{X_2}{2} - \cancel{\frac{1}{2}\sin(X_1)\cos(X_1)}^{0} - \cancel{\frac{X_1}{2}}\right]^{\to 0}$$
$$+ 2 r_{wp} \tan(\alpha) \left\{ \frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right] \cancel{- \frac{\sin(X_1)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_1)\right]^{1/2} - \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_1)\right]}^{\to 0} \right\}$$
$$+ \frac{4 r_{ds}}{\sin(2\alpha)} (b_o - r_{wp} + r_{ds}) [\sin(X_3) - \sin(X_2)]$$
$$- \frac{4 r_{ds}^2}{\sin(2\alpha)} \left[\frac{1}{2}\sin(X_3)\cos(X_3) + \frac{X_3}{2} - \frac{1}{2}\sin(X_2)\cos(X_2) - \frac{X_2}{2}\right]$$
$$+ \frac{4 r_{ds} r_{wp}}{\sin(2\alpha)} \left\{ \frac{\sin(X_3)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_3)\right]^{1/2} + \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_3)\right] - \frac{\sin(X_2)}{2}\left[1 - \frac{r_{ds}^2}{r_{wp}^2}\sin^2(X_2)\right]^{1/2} - \frac{r_{wp}}{2 r_{ds}} \sin^{-1}\left[\frac{r_{ds}}{r_{wp}}\sin(X_2)\right] \right\}$$

where

$X_1 = 0$, $X_2 = {}_{max}\theta_{ds}^*$, and $X_3 = {}_{max}\theta_{ds}$; $\alpha \le \sin^{-1}\left(\frac{b_o}{t_{bh}}\right)$

X_one X_two X_three

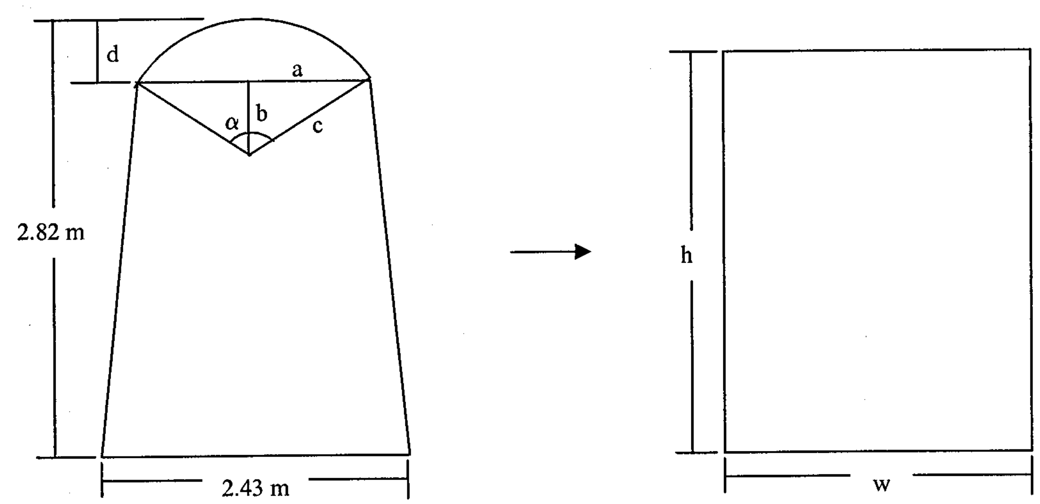
when $\alpha \to 0$ $X_2 \to X_3$

4-17-2006 George Adams

An updated mechanical failure abstraction was implemented for version 5.1 beta of the tpa code. Portions of the abstraction involving drift failure were separated from the drip shield and waste package mechanical failure abstraction. Drift failure was placed in a new module, DRIFTFAIL. Drip shield and waste package mechanical failure was placed in a new MECHFAIL module. A drip shield equivalent height was needed for the updated mechanical failure abstraction. The diagram below shows how the drip shield equivalent height and width were determined.

Drip Shield Equivalent Height Calculation

George Adams 4-17-2006



Drip Shield Width at Base (m)	2.430
Drip Shield Height (m)	2.820
Drip Shield Width at Crown (m) {2a}	2.222
Drip Shield Crown Radius (m) {c}	1.300
Dimension: a (m)	1.111
Dimension: b (m)	0.675
Angle α (radians)	1.025
Area of Triangle (m^2)	0.750
Area of Sector (m^2)	0.866
Area of Segment (m^2)	0.116
Dimension: d (m)	0.625
Area of Trapezoid (m^2)	5.106
Total Area of Drip Shield	5.222
Equivalent Height of Rectangle: h (m)	2.508
Equivalent Width of Rectangle: w (m)	2.082

4-17-2006 George Adams

The mechanical failure module, MECHFAIL, is invoked twice for each subarea. It is first invoked for drip shield mechanical failure. It is invoked a second time to calculate waste package mechanical failure. The initial portion of the data files for drip shield and waste package mechanical failure are shown below. These portions of the files show the coefficients used in the equations.

George Adams 4-17-2006

```
TITLE - mechfail_ds.def
DATE/TIME: Tue Mar 14 16:27:12 2006
:Debug flag (1=debug, 0=no debug)
          0
:Mechanical Failure(DS=1, WP=2)
          1
:Equation 1 coefficients (vertical load carrying capacity)
  0.00000E+00  1.00000E+00 -5.27066E+05  2.50593E+06 -4.81848E+06  4.61522E+06 -1.97748E+06 -1.27821E+05
5.05056E+05 -2.11140E+05  4.07787E+04 -6.02812E+03  1.12574E+03
:Equation 2 coefficients (drip shield thickness region 1)
  0.00000E+00  7.50000E-03  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
:Equation 3 coefficients (drip shield thickness region 2)
  7.50000E-03  1.50000E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  1.00000E+02  2.50000E-01
:Equation 4 coefficients (drip shield yield factor)
  0.00000E+00  1.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  5.00000E-01
:Number of tpa time steps
        201
:Number of seismic events
          3
:Subarea identifier
          1
:Seismicity flag (yes=1,no=0)
          1
:Start time [yr]
 1.00000E+02
:Time array [yr]
  0.00000E+00  2.31016E+00  4.67440E+00  7.09399E+00  9.57023E+00  1.21044E+01  1.46980E+01  1.73522E+01
2.00686E+01  2.28486E+01  2.56937E+01  2.86054E+01  3.15852E+01  3.46349E+01  3.77559E+01  4.09499E+01
4.42188E+01  4.75642E+01  5.09879E+01  5.44917E+01  5.80776E+01  6.17474E+01  6.55032E+01  6.93469E+01
7.32805E+01  7.73063E+01  8.14263E+01  8.56428E+01  8.99579E+01  9.43741E+01  9.88937E+01  1.03519E+02
1.08253E+02  1.13097E+02  1.18055E+02  1.23129E+02  1.28322E+02  1.33636E+02  1.39075E+02  1.44641E+02
1.50338E+02  1.56167E+02  1.62134E+02  1.68240E+02  1.74489E+02  1.80884E+02  1.87429E+02  1.94127E+02
2.00982E+02  2.07997E+02  2.15177E+02  2.22524E+02  2.30044E+02  2.37740E+02  2.45616E+02  2.53676E+02
2.61926E+02  2.70368E+02  2.79008E+02  2.87850E+02  2.96899E+02  3.06160E+02  3.15638E+02  3.25337E+02
3.35264E+02  3.45423E+02  3.55820E+02  3.66461E+02  3.77350E+02  3.88495E+02  3.99900E+02  4.11572E+02
4.23518E+02  4.35743E+02  4.48255E+02  4.61059E+02  4.74163E+02  4.87574E+02  5.01299E+02  5.15346E+02
5.29721E+02  5.44432E+02  5.59488E+02  5.74897E+02  5.90666E+02  6.06805E+02  6.23321E+02  6.40224E+02
```

George Adams 4-17-2006

```
TITLE - mechfail_wp.def
DATE/TIME: Tue Mar 14 16:27:14 2006
:Debug flag (1=debug, 0=no debug)
          0
:Mechanical Failure(DS=1, WP=2)
          2
:Equation 1 coefficients (force per unit length region 1)
  0.00000E+00  2.50000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  9.58900E+04
:Equation 2 coefficients (force per unit length region 2)
  2.50000E+00  5.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00  3.06779E+03 -3.60147E+03 -4.16820E+04  9.58900E+04
:Equation 3 coefficients (force per unit length region 3)
  5.00000E+00  1.00000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00 -1.47223E+01  3.06875E+02 -2.16832E+03  1.71100E+04
:Equation 4 coefficients (force per unit length region 4)
  1.00000E+01  1.50000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00 -2.13350E+00  2.87359E+01 -2.03742E+02  1.21000E+04
:Equation 5 coefficients (force per unit length region 5)
  1.50000E+01  2.00000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00 -6.07300E-01  6.79566E+00 -7.63958E+01  1.15330E+04
:Equation 6 coefficients (force per unit length region 6)
  2.00000E+01  2.50000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00  1.90453E+00 -8.88531E+00 -5.39867E+01  1.12450E+04
:Equation 7 coefficients (force per unit length region 7)
  2.50000E+01  3.00000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00 -1.09867E+00  8.24000E+00  0.00000E+00  1.09910E+04
:Equation 8 coefficients (force per unit length region 8)
  3.00000E+01  3.50000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.10597E+04
:Equation 9 coefficients (force per unit length region 9)
  3.50000E+01  4.50000E+01  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+
00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  1.10597E+04
:Equation 10 coefficients (wp outer layer multiplier)
  0.00000E+00  2.00000E-02  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00 -2.09642E+10  1.67238E+
09 -5.54719E+07  1.00491E+06 -1.13328E+04  1.10497E+02  1.56751E-01
:Number of tpa time steps
        201
:Number of seismic events
          3
:Subarea identifier
          1
:Seismicity flag (yes=1,no=0)
          1
```


4-17-2006 George Adams

The force per unit length coefficients are shown below.

George Adams 4-17-2006

3.06779E3	-3.60147E3	-4.16820E4	9.58900E4
-1.47223E1	3.06875E2	-2.16832E3	1.71100E4
-2.13350E0	2.87359E1	-2.03742E2	1.21000E4
-6.07300E-1	6.79566E0	-7.63958E1	1.15330E4
1.90453E0	-8.88531E0	-5.39867E1	1.12450E4
-1.09867E0	8.24000E0	0	1.09910E4
0	0	0	1.10597E4
0	0	0	1.10597E4

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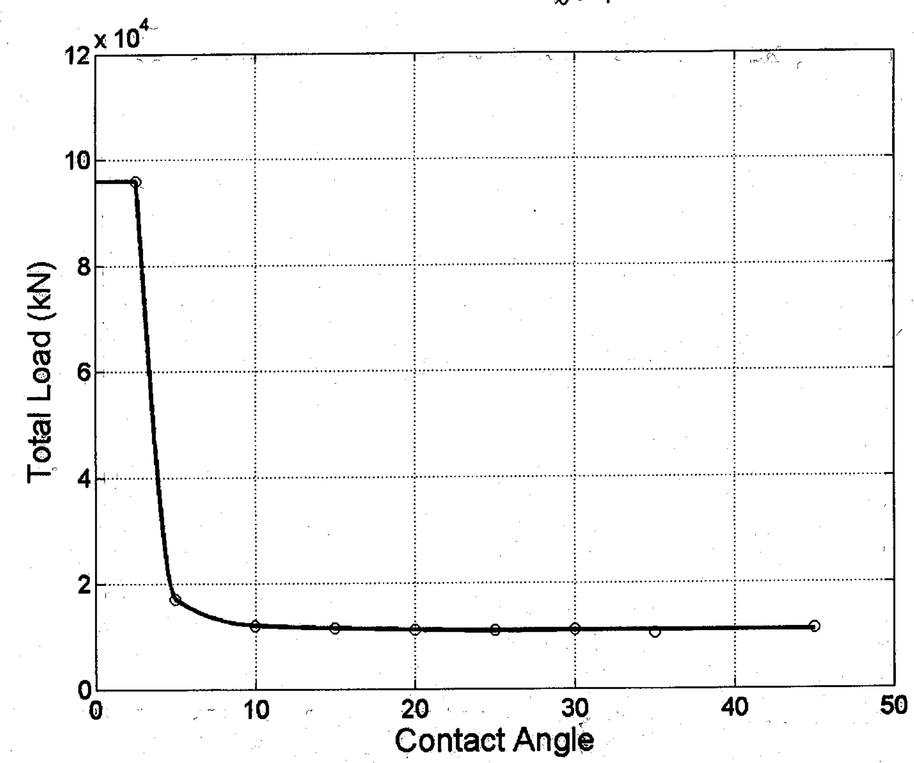

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x = [2.5000 5.0000 10.0000 15.0000 20.0000 25.0000 30.0000 35.0000 45.0000]

<u>between 0 ≤ x ≤ 2.5:</u> $y_0 = 95890$

<u>between 2.5 ≤ x ≤ 5:</u>

1.0e+004 *
0.30677893695921 -0.36014734239802 -4.16820000000000 9.58900000000000

$y_1 = c_1(1)*[x' - x(1)]^3 + c_1(2)*[x' - x(1)]^2 + c_1(3)*[x' - x(1)] + c_1(4)$

<u>between 5 ≤ x ≤ 10:</u>

1.0e+004 *
-0.00147223294686 0.03068749353528 -0.21683164400494 1.71100000000000

$y_2 = c_2(1)*[x' - x(2)]^3 + c_2(2)*[x' - x(2)]^2 + c_2(3)*[x' - x(2)] + c_2(4)$

<u>between 10 ≤ x ≤ 15:</u>

1.0e+004 *
-0.00021335034455 0.00287358765607 -0.02037417966649 1.21000000000000

<u>between 15 ≤ x ≤ 20:</u>

1.0e+004 *
-0.00006073002136 0.00067956589629 -0.00763957894737 1.15330000000000

<u>between 20 ≤ x ≤ 25:</u>

1.0e+004 *
0.00019045313653 -0.00088853136531 -0.00539867158672 1.12450000000000

<u>between 25 ≤ x ≤ 30:</u>

1.0e+004 *
-0.00010986666667 0.00082400000000 0 1.09910000000000

<u>between 30 ≤ x ≤ 35:</u>

1.0e+004 *
0 0 0 1.10596666666667

<u>between 35 ≤ x ≤ 45:</u>

1.0e+004 *
0 0 0 1.10596666666667

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The drip shield vertical load carrying capacity coefficients are shown below.

Interp_ave_lat_to_vert_load2.txt

```
-5.27066E5
2.50593E6
-4.81848E6
4.61522E6
-1.97748E6
-1.27821E5
5.05056E5
-2.11140E5
4.07787E4
-6.02812E3
1.12574E3
```

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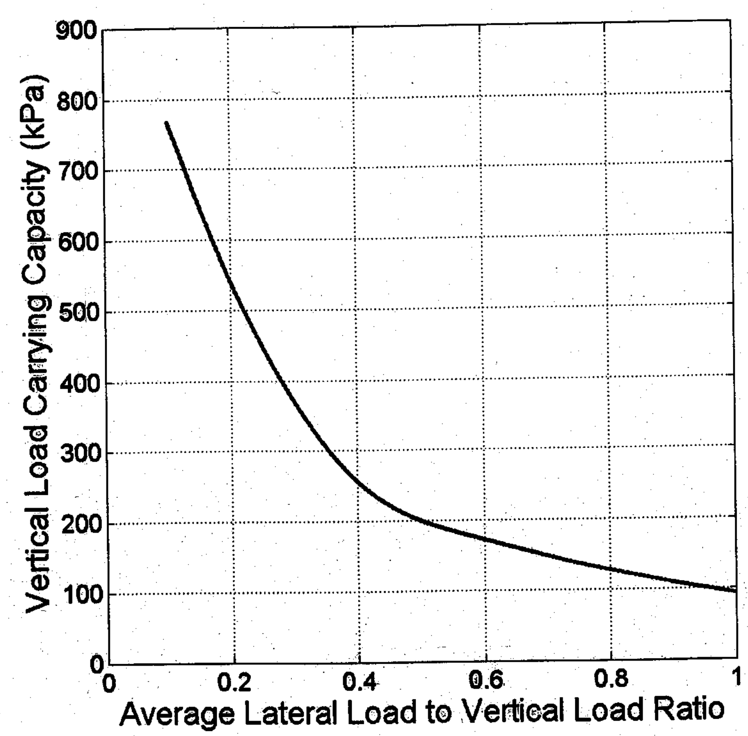

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The waste package outer layer multiplier coefficients are shown below.

Interp_wp_thickness_multiplier.txt

```
-2.09642E-8
1.67238E-6
-5.54719E-5
1.00491E-3
-1.13328E-2
1.10497E-1
1.56751E-1
```

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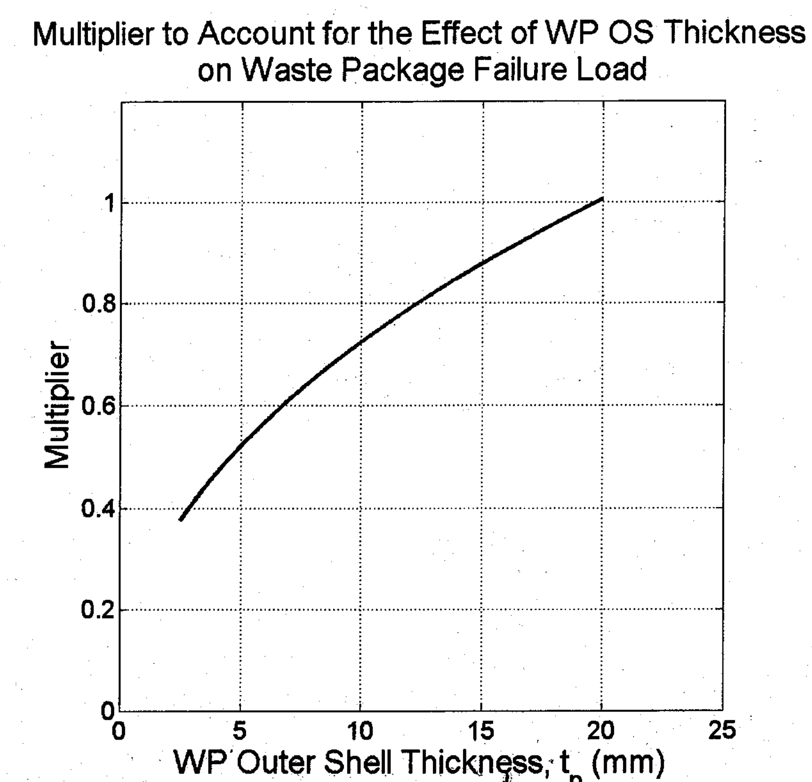

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[signature] 4-17-2006

The mechfail abstraction was implemented in version 5.1beta of the tpa code. The MECHFAIL module was implemented under Software Change Report (SCR) 609. The DRIFTFAIL module was implemented under SCR 610. Scientific Notebook 612-8E describes the implementation of MECHFAIL under SCR 609 and the testing of DRIFTFAIL under SCR 610.

[signature] 9-4-2007

GEOSCIENCES AND ENGINEERING DIVISION

SCIENTIFIC NOTEBOOK REVIEW CHECKLIST RECORD

Scientific Notebook No. 410 Project Numbers: 20.06002.01.354

Accomplished	
✓	1. Initial entries per QAP-001
✓	2. Dating of entries
✓	3. Corrections (crossed out, one line through w/initials/date)
✓	4. No White out used
✓	5. Page number visible on copy or original notebook
✓	6. In process entries per QAP-001
✓	7. Figure information present
✓	8. Text readable
✓ None	9. Copyrighted material is identified
✓	10. Permanent ink or type only
✓	11. Signing of entries (not required on each page)
None	12. Electronic media in the scientific notebook properly labeled
✓	13. NRC Supplementary Scientific Notebook Questions are addressed.
✓	14. The independent, two person verification required by AP-019, Section 5.2.1.2(b) is complete

Any discrepancies must be resolved before notebook closeout.

I have reviewed this scientific notebook and find it in agreement with QAP-001.

[signature] 10-12-07

Manager's Signature Date

Attach this completed form to the last page of the notebook.