Meeting Minutes

Engineering/Minerals
Tonto National Forest
Phoenix, AZ

To: Project Record

From: Donna Morey, SWCA

Re: Resolution Geology/Subsidence Workgroup Meeting 3/16/2018

Attendees:

USFS: Greg Olsen, Judd Sampson, Mary Rasmussen, Tim Stroope, Joe Gurrieri
SWCA: Chris Garrett, Donna Morey, Charles Coyle, Nick Enos, Mike Henderson, Amir Karami, Laurie Brandt, Chris Horyza, Rex Bryan, Diana Cook
RCM: Vicky Peacey, Cameo Flood, Gert Van Hout, Jacques Tshishens, Jim Butler, Matt Pierce

Handouts:

Agenda
Presentation from Resolution (PPT)

Discussion:

EIS Authors have begun writing the Affected Environment, but not able to begin on Env. Consequences.

Internal deadline for all moving parts in approx. 6 weeks – end of May.

Presentation of New information

Numerous faults are incorporated into the model – implicitly, not discrete interfaces.

- ? How do you determine defect from intact rock samples? Are they infills or veining?
    - o Many rocks seen at site have veining or defaulting. Could consider amount of defects and degrade strength – but hard as there are almost no intact samples. All tests were done on defaulted rock – over 75% failed by defect. Yes, most are veins and veinlets. No downgrading is done as tests are done on defaulted rock, only systematic downgrading is due to scale.
- ? Is all rock defective or just ore, not over burden?
    - o Apache Leap Tuft is mainly homogeneous; White tail has a lot of clast; deep kvs, diabase, and quartz are highly defectively.

The table in the table are same as submitted in Jan 2018 submittal from Resolution.

- ? Why were faults not modeled discreetly?
    - o They have a finite thickness and act as a zone, most are not open and persisting.
- ? If these were treated as faults in the modeling would there be different results in the model?
    - o No.

Process Point: Model properties are based on field interpretations, most information in hand from early 2017, and recent submittal mid-March 2018 from Harry Parker.

Conservativeness of Model: Resolution wants to be conservative. Faults are characterized as weaker than surrounding rock, are persistent.

- ? Are faults sized in model, what size?
  - o Faults are shown as 2-3 zones thick to allow slip thru mesh of model, not actual size.
- ? What would a minimum zone size be? A - Unsure, will verify, but would assume 5m.
  - o Faults downgraded by both UCS and GSI at same time to 75% of initial strength.

Slide 6 – reality is N/S, not "assumed" as shown on slide

- ? Are there any in-situ measurements to verify sigma v and h?
  - o Yes, in the January report attachments.
- ? What would expected size of broken rock be?
  - o Low stress = big blocks (car and large sized at beginning of mining underneath), high stress = small blocks (fist/water glass in middle throughout production) low stress = big blocks again at top near surface – can be affected by joint sizing, but assume car size again.
- ? What is model cell size?
  - o It is scaled per zone.

Slides starting on 8 – black line is fracture limit (for visual viewing), white is cave zone. Blue expended lines are shear zones, not faults.

- ? If plots show year 40 – when is steady state?
  - o The crater will deepen slightly over time, due to compaction, but limits will not be expected to change.
- ? Would like to explain to public what might happen with a maximum reasonable earthquake would do to cave?
  - o Subsidence would be on private land at that point, could expect more unraveling from around edge.
- ? The volume of the material being mined is about 1.5 billion tons. What's the volume of material inside the subsidence zone after mining?
  - o Will need to respond later with this answer.
- ? Is there a way to consider adaptive mgmt. during operations?
  - o Yes, that is in GPO to mine panel #s, will mine away from Apache Leap and modify as needed. If subsidence goes too far west it will impact shafts and Resolution would be unable to mine anymore.
- ? This would be a slow process, are there more visuals than just Year 40?
  - o Yes, 10, 20, and 40 years are all shown in topographic images by resolution

Slides 11 - Fracture limit is shown – rounded out to cover all edges of

Monte Carlo Approach used to plot many changes between GSI and UCS. This is an emergent distribution, not forced to a bell curve of standard deviation. The full model was not run as Monte Carlo.

- 30th Percentile references – Pierce, 2010 – Bingham mine, Lorig et al., 2018. Why does 27 % show when Peirce sees 30% and Lorig sees closer to 40%? – It was a data driven choice based on core logging.
- The parameter distribution is bootstrapped by actual results.

To Summarize for public:

1. Rock strength affects the extent of subsidence. Weaker strength would show larger extent and lower slopes where stronger rock strength would be a smaller extent with a larger depth.
2. We have measurements of various kinds to put together rock strength. Based on field and only 27-30% are weaker than we are estimating. Of the rocks seen in field, 70% of rocks are stronger than we are representing in the model.
3. One point will never control overall performance.

? How can we tell the public that the extent will not continue to grow after mining stops?
  - Refer to report for 5 year increments to show limit of growth extent.
  - Model cannot show after mine stop unless something is being taken out. Change after mining can't be modeled, but could be described visually – soil moving from sides to bottom or plants taking hold and growing. Field experience from other mines is what will describe this.

? How do we show the public that Apache Leap will not be affected with subsidence coming this close?
  - The lines shown (fracture line), tilt would affect the leap more than fracture.

Design of monitoring – will be needed prior to DEIS to show how impacts will be limited.
Observational Monitoring – does real world observations fall within normal range (examples can be seen when searching for Ralph Peck and Observational Methods)

Deliverable

Geologic Data & Subsidence Modeling Evaluation Report

- Summary of data reviewed and review process - Laurie
- Reference standards/Best Practices
- Review and conclusions on adequacy of internal RCM QA/QC procedures
- Review of RCM geologic interpretations
  - Structure/fault
  - Rock property interpretations
  - Reasonableness of interpretations
  - If applicable, alternative interpretations
- Review of Itasca subsidence model - Amir
- Credentials of reviewers

Schedule

3/16/18	Today's meeting #4
4/2	receipt of sensitivity model report
April	2 or 3 USFS/SWCA calls – data requests/clarifications/questions
4/16	RCM respond to 3/16 requests
4/27	submit data request to RCM

5/15	meeting #5
5/30	internal drafts due for first 3 sections of report
6/5	deadline for RCM response to data requests
6/12	proposed geology/subsidence meeting #6
June/July	mostly internal writing
7/30	internal drafts due for last 2 sections
8/30	Review cycle & finalize and move on to EIS

Review Action Items from last meeting – send out today to all group members

Action Items:

1. SWCA to send action items from last meeting
2. RCM to provide video/visual representations of subsidence
3. SWCA search for narrative write up about how samples used for rock testing are representative of area.
4. Matt to check for minimum zone size for faults for Amir?
5. Matt to find volume of material inside the subsidence zone after mining?
6. Drill Core photos for those crossing at boundary faults
7. Resolution to add a plot vertical displacement contours for each scenario, 25 m intervals, at 10, 20, and 40 years
8. Point Histories – Ground surface – shaft 9, center of crater, oak flat campground, Devil's canyon, Apache Leap boundary, near cave zone boundary (Amir will draw additional based on lithology and provide to RCM). Needs to see displacement (horizontal and vertical), angle of distortion.
9. SW-NE Cross sections (public consumption with no vertical assumption to be done later)
10. Resolution to add statement to report about information on mine not propagating further after mining with information known from other mines.
11. Resolution to submit more detailed monitoring plans.
12. Add to proponent mitigation that Resolution is not mining all ore to avoid impacts to Apache Leap and US60.
13. Further discussion of difference between mitigation and design features

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Agenda

To: Attendees, Project File

From: Chris Garrett, SWCA

CC:

Date: 3/16/2018

Re: **Resolution Copper Mine – Geology\Subsidence Workgroup Meeting 3/16/2018**

Location:

In Person:

SWCA, 20 E. Thomas Road, Suite 1700

Visitor parking is in the adjacent garage with entrances off Second Street or Catalina Drive. You will need to check in at the security desk in the lobby, to be let up to the 17th floor. Please bring your ticket for validation by our receptionist.

Webinar Information:

Webinar access: https://global.gotomeeting.com/join/896636613

Call in phone line if you do not want to use your computer audio: (312) 757-3121; Access Code: 896-636-613

Discussion Points:

9:00 – 9:15	Introductions and project updates
9:15 – 10:30	Review of subsidence sensitivity modeling runs (Resolution)
10:30 – 10:45	Break
10:45 – 12:00	Continued review of subsidence sensitivity modeling runs and follow-up on previous questions
12:00 – 12:45	Lunch
12:45 – 2:00	Continued review of subsidence sensitivity modeling runs and follow-up on previous questions
2:00 – 2:15	Break

2:15 – 3:15	Discussion of deliverables and schedule
3:15 – 3:30	Review next steps/action items

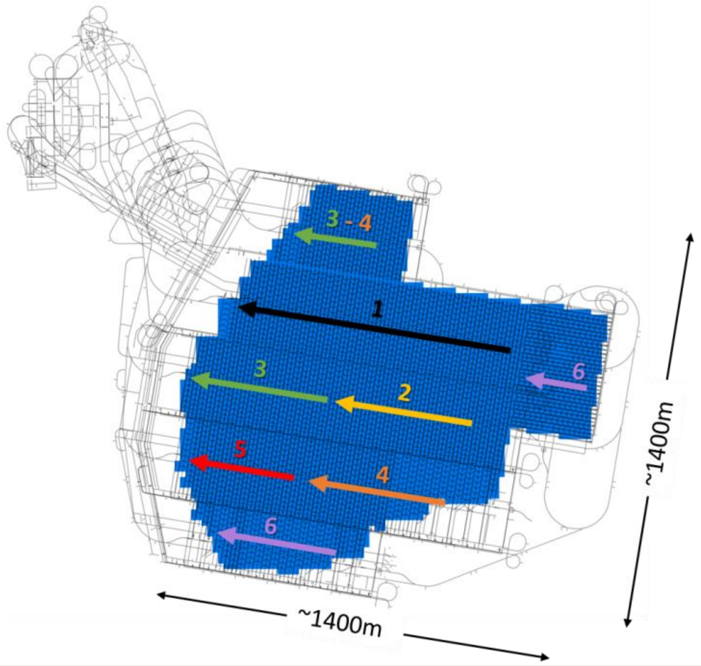
SENSITIVITY STUDY OF MODEL PARAMETERS IN THE CAVING PREDICTIONS FOR RESOLUTION COPPER MINE

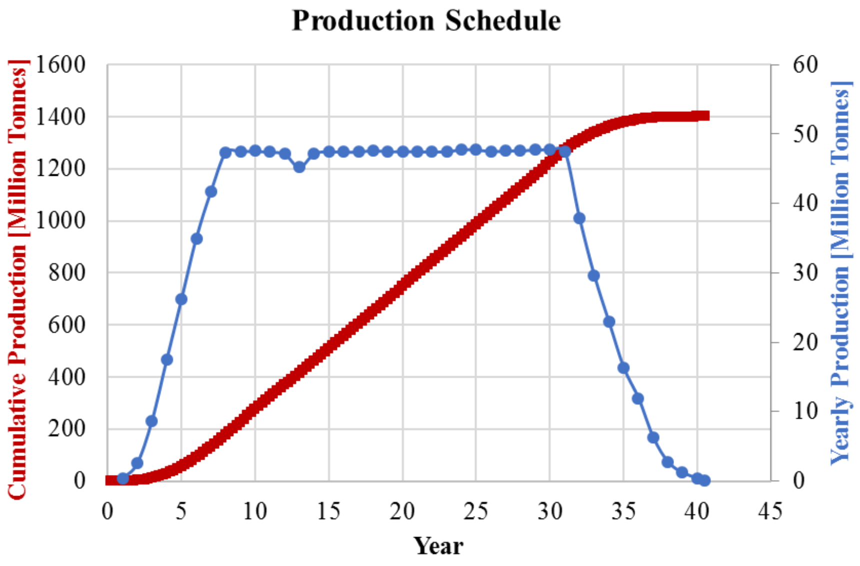
MINE PLAN OF OPERATIONS

Tryana Garza-Cruz and Matt Pierce

Geometry and Production

- Extraction level depth ~1900m
- Blind orebody with max. column heights ~500m





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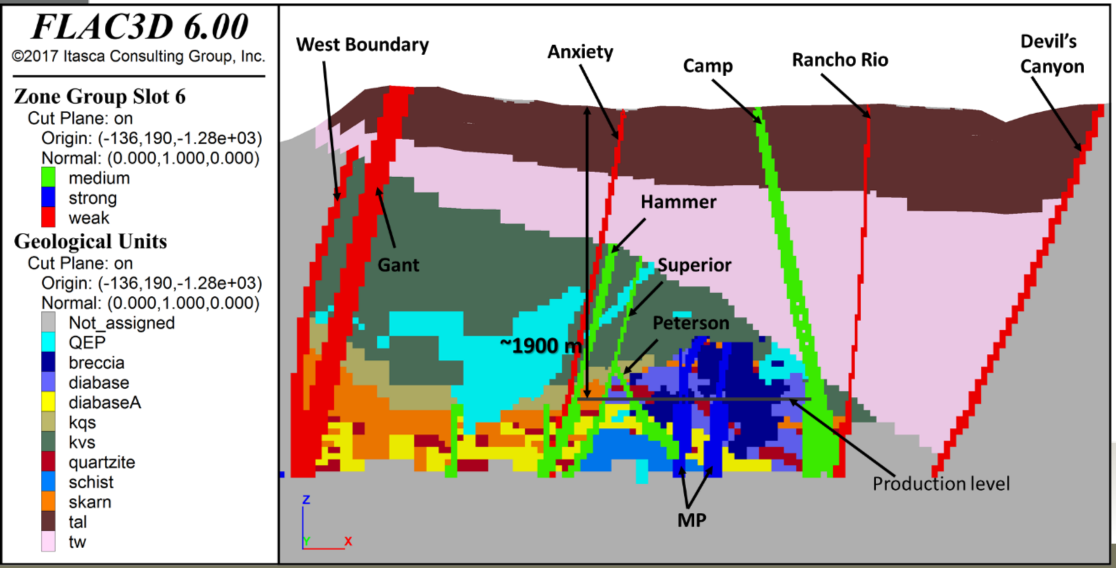
Rock Mass Properties

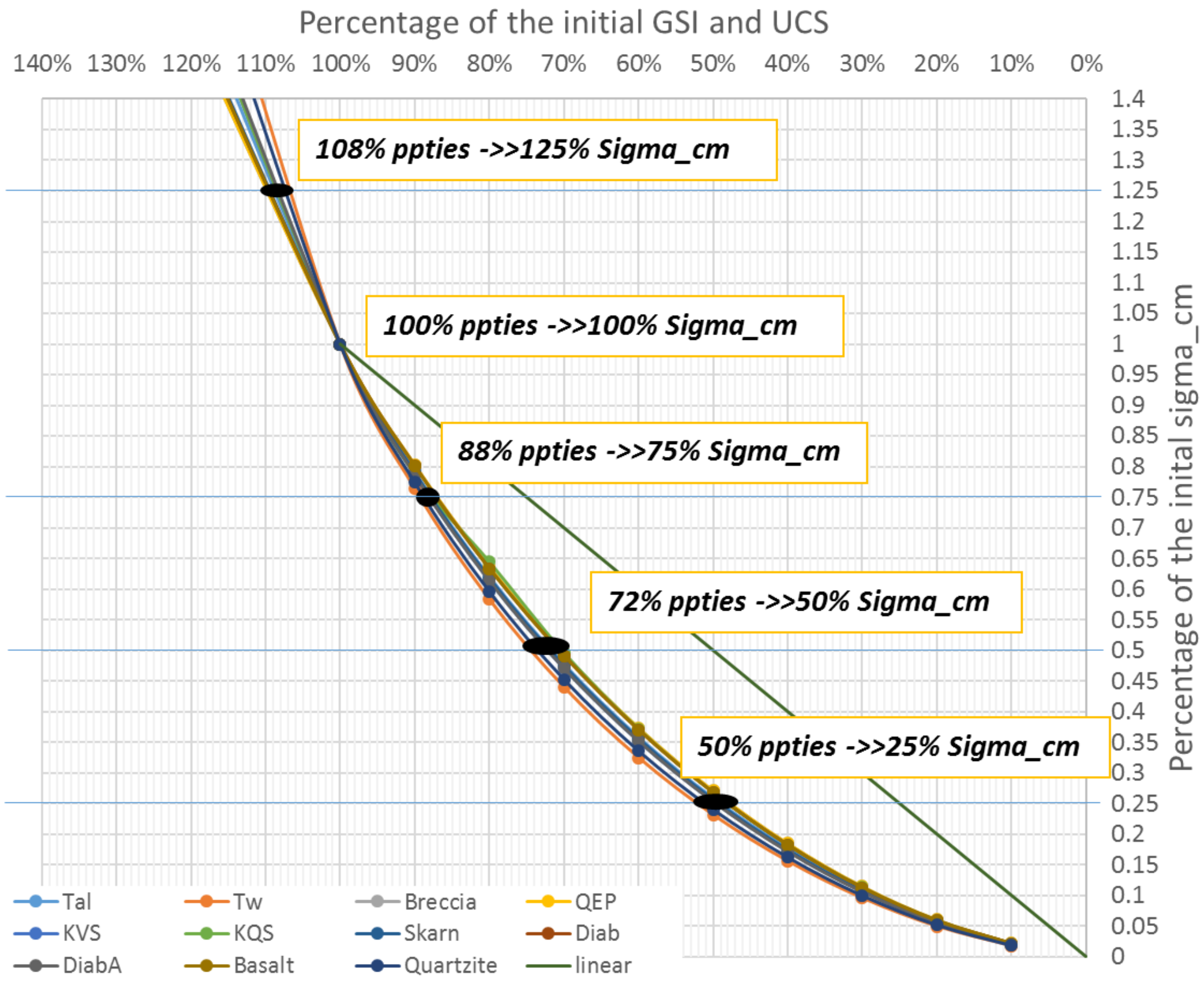
- Faults modeled implicitly
- Geological units defined based on provided DXFs
- Geotechnical properties from *RCML GTC 2016_0202 Material Properties for Microblock Modeling.docx*



	Data				3D Model Parameters					
								Peak Strength		
Unit	GSI	σ_d (MPa)	m_d	E_d (GPa)	Density	E_{rm} (Gpa)	v	m_{rm}	s	a
Diabase, Basalt	54	54	12	27	2600	10.4	0.24	2.3	0.0060	0.5
Diabase with anhydrite	62	106	15	40	2600	22.6	0.23	3.9	0.0147	0.5
Breccia, QEP	54	55	15	31	2600	12.0	0.24	2.9	0.0060	0.5
Quartzite	69	103	21	39	2600	27.8	0.22	6.9	0.0319	0.5
Tal (Apache Leap Tuff)	64	66	30	30	2600	18.0	0.22	8.2	0.0175	0.5
Tw (Whitetail)	73	23	22	10	2600	7.8	0.21	8.3	0.0476	0.5
KVS, KQS	66	46	30	30	2600	19.3	0.22	8.8	0.0217	0.5
Skarn	63	59	22	40	2600	23.1	0.23	5.8	0.0155	0.5

Rock Mass Strength

- σ_{cm} is the unconfined compressive strength defined by a Mohr-Coulomb fit to the Hoek-Brown curve over a range of confinement from 0 to 25% of the laboratory intact UCS.
- In order to simplify the process of equally varying the rock-mass global-strength (a function of both GSI and UCS) of all units, a relationship between the effect of equally varying both the GSI and UCS to obtain the resulting global strength was generated



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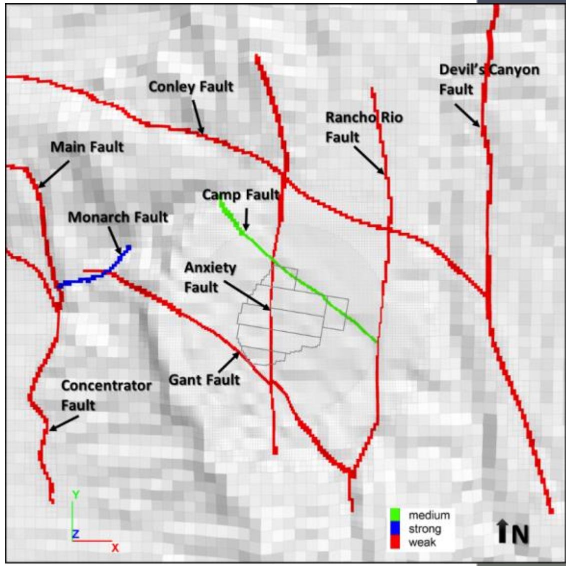
Fault Ranking

- Faults were classified as strong moderate or weak based on description provided by Resolution
  - Strongly annealed faults (strong)
  - Mixed or moderately annealed faults (moderate)
  - Slickensided and/or gouge (weak)

Strong (75% σ_{cm})	Moderate (50% σ_{cm})	Weak (residual prop)
Manske	Andesite	326 Pump Station
Monarch	Camp	Anxiety
MP-1	Hammer N	Concentrator
MP-2	Hammer S	Conley Spring
MP-3	Hammer SW	Devils Canyon
South Boundary	Intergraben	Gant E
	North Boundary A	Gant W
	North Boundary B	Main
	North Boundary C	North Boundary
	Paul	Rancho Rio
	Paul S	West Boundary
	Peterson	
	Superior	
	Superior A	



	Base Case	Strong Case	Weak Case
Strong Faults	75% σ_{cm}	88% σ_{cm}	50% σ_{cm}
Medium Faults	50% σ_{cm}	72% σ_{cm}	25% σ_{cm}
Weak Faults	Cohesion = 0, tensile strength = 0, friction = 35°	Cohesion = 0, tensile strength = 0, friction = 35°	Cohesion = 0, tensile strength = 0, friction = 25°

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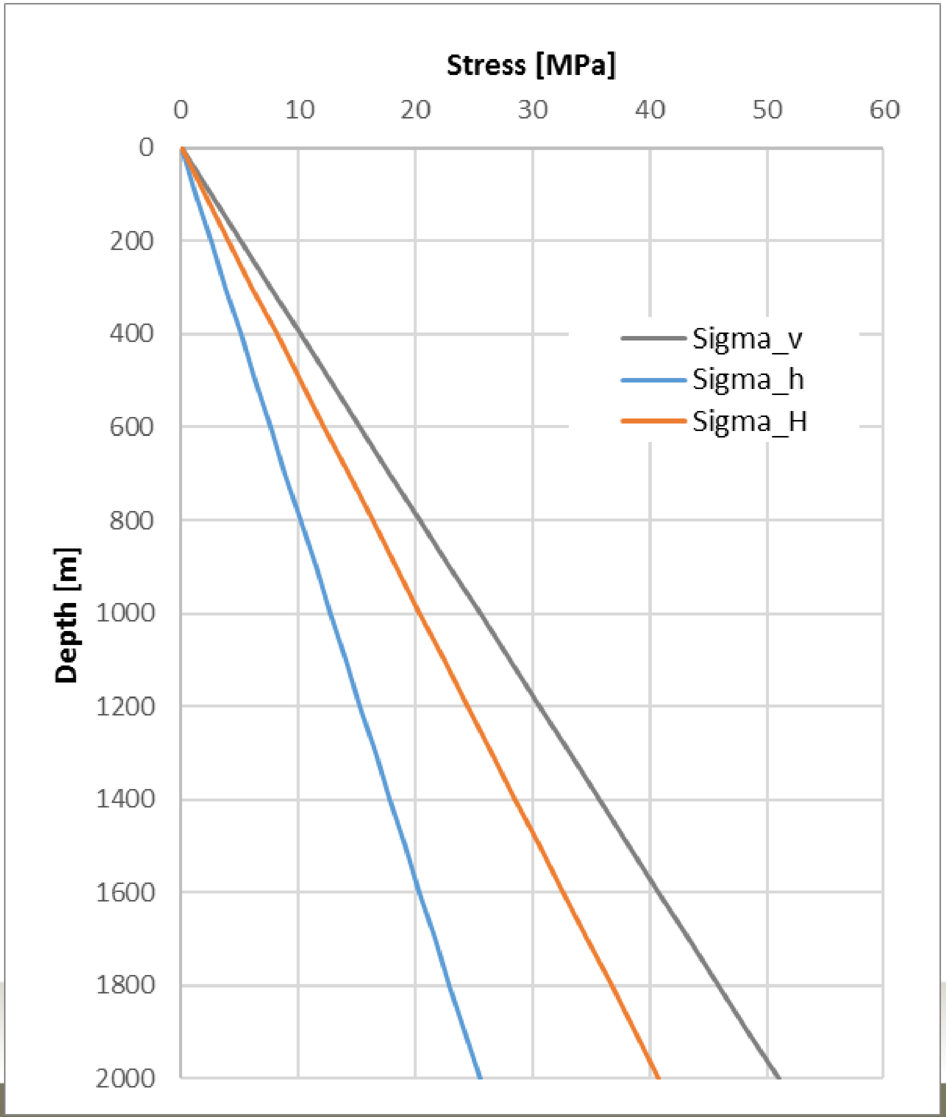
In-situ Stress

Principal Stress	Base Case Magnitude	Sensitivity Study 75% K0	125% K0
σ_V	25.5*z [km]	25.5*z [km]	25.5*z [km]
σ_H	20.4*z [km]	15.3*z [km]	25.5*z [km]
σ_h	12.75*z [km]	9.56*z [km]	15.94*z [km]

- Base case: σ_H is assumed N-S



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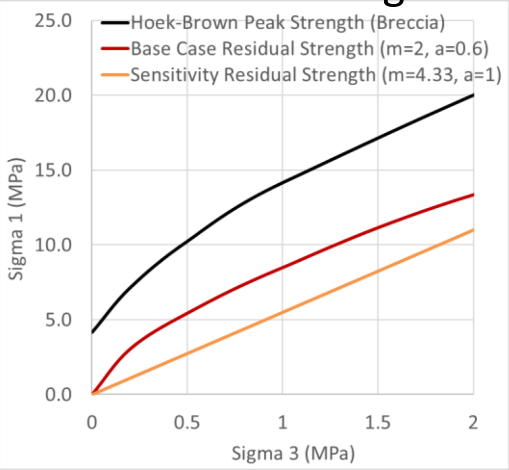
Cases Examined

Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Original Strong	100%	Strong Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 1	75% σ_{cm}	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 2	125% σ_{cm}	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 3	100%	Weak Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 4	100%	Base Case	Sensitivity	0.67 (40% porosity)	Base Case	N-S
Sensitivity 5	100%	Base Case	Base Case	0.5 (30% porosity)	Base Case	N-S
Sensitivity 6	100%	Base Case	Base Case	0.67 (40% porosity)	125% K0	N-S
Sensitivity 7	100%	Base Case	Base Case	0.67 (40% porosity)	75% K0	N-S
Sensitivity 8	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	E-W

Fault Properties

	Base Case	Strong Case	Weak Case
Strong Faults	75% σ_{cm}	88% σ_{cm}	50% σ_{cm}
Medium Faults	50% σ_{cm}	72% σ_{cm}	25% σ_{cm}
Weak Faults	Cohesion = 0, tensile strength = 0, friction = 35°	Cohesion = 0, tensile strength = 0, friction = 35°	Cohesion = 0, tensile strength = 0, friction = 25°

Residual Strength

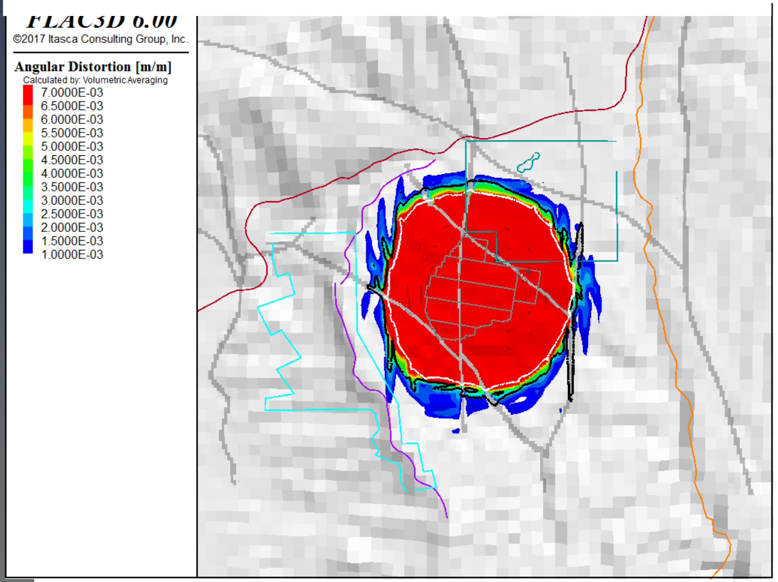


In-situ stress

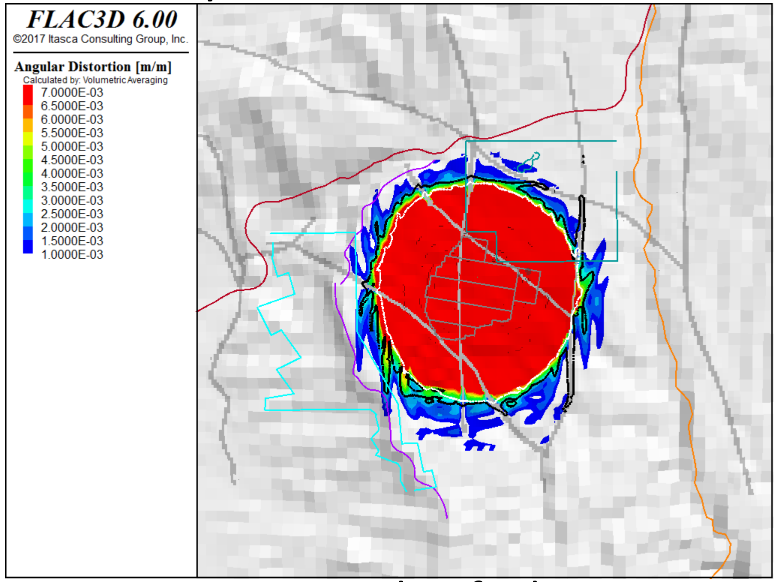
	Base Case	Sensitivity Study	
Principal Stress	Magnitude	75% K0	125% K0
σ_V	25.5*z [km]	25.5*z [km]	25.5*z [km]
σ_H	20.4*z [km]	15.3*z [km]	25.5*z [km]
σ_h	12.75*z [km]	9.56*z [km]	15.94*z [km]

Angular Distortion

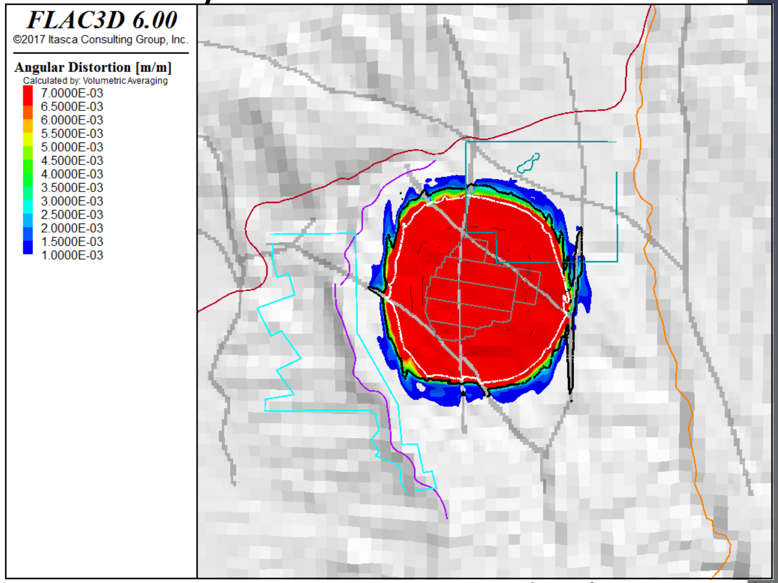
Base Case



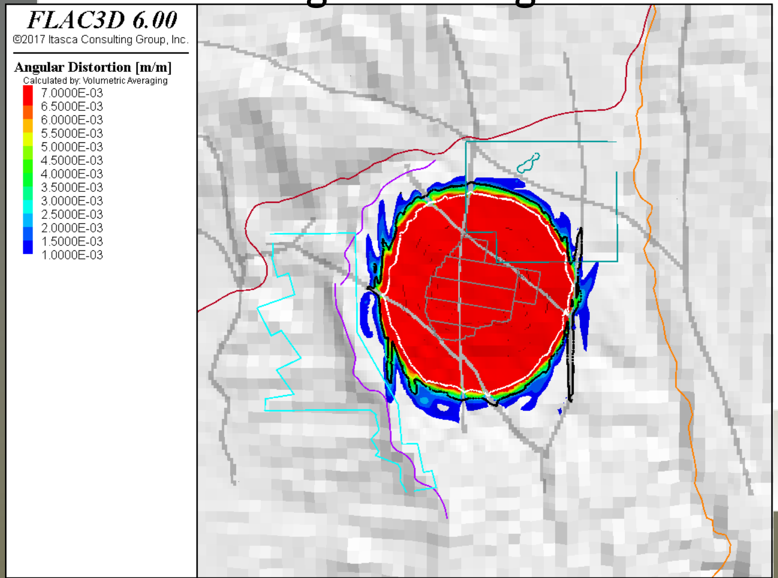
Sensitivity 1 – 75% σcm



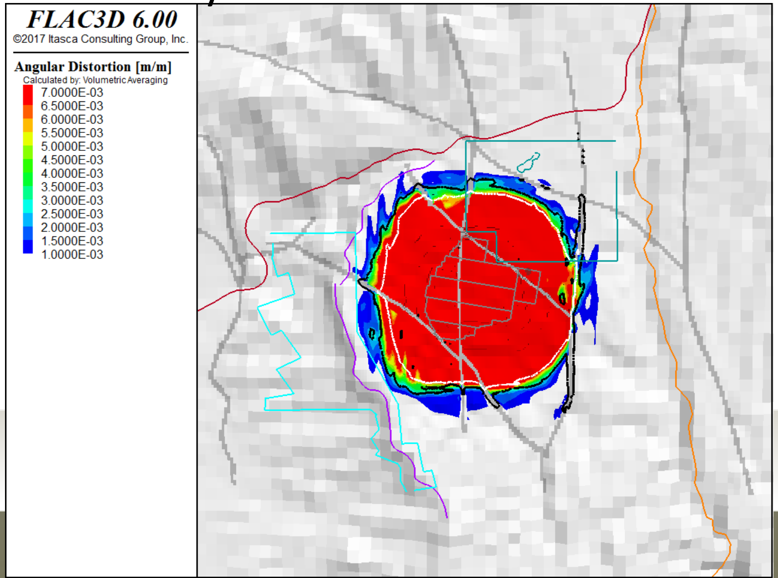
Sensitivity 2 – 125% σcm



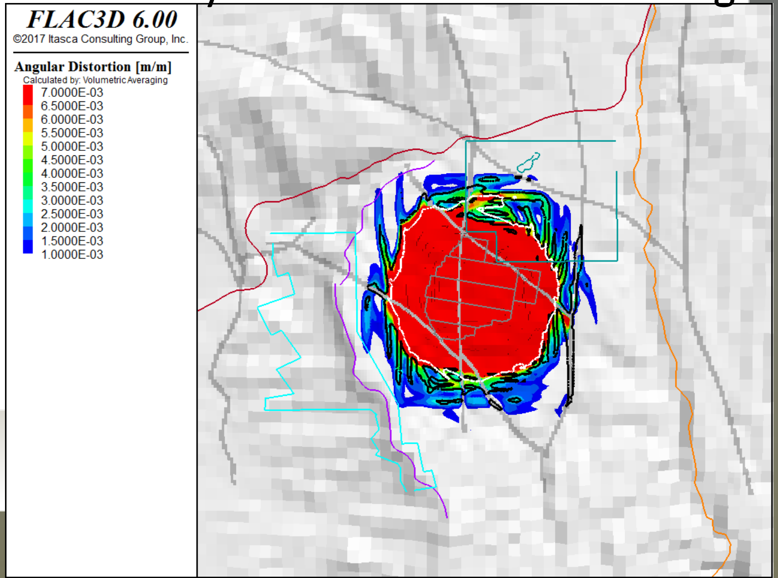
Original Strong



Sensitivity 3 – Weaker faults

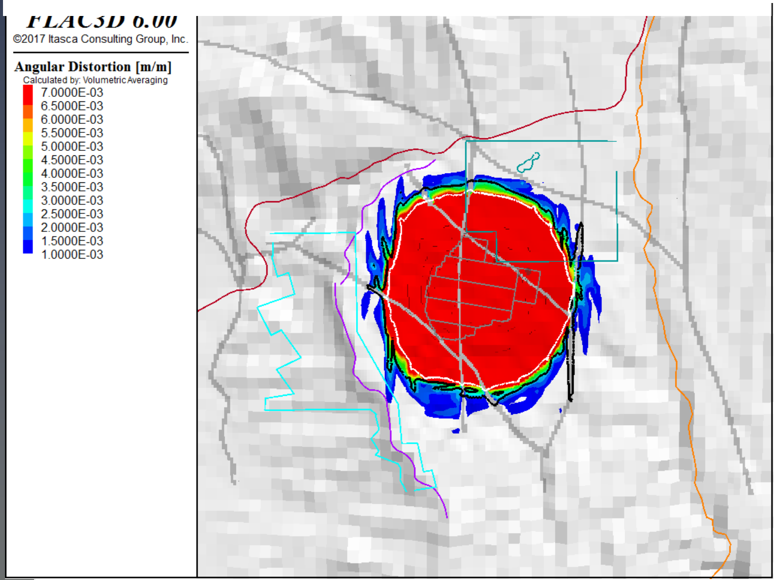


Sensitivity 4 – Lower Residual Strength

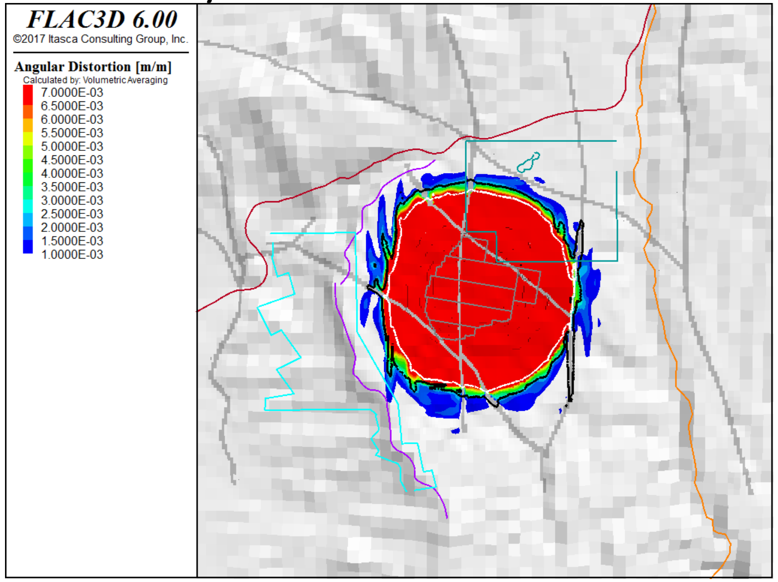


Angular Distortion

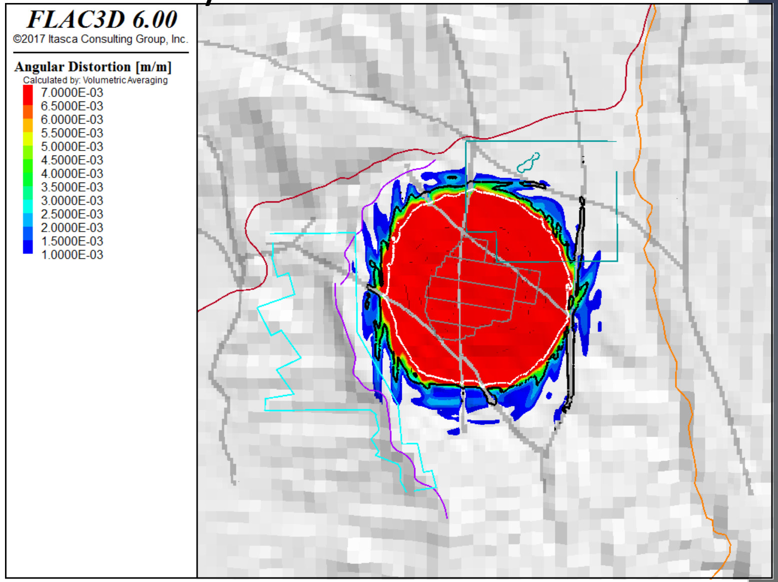
Base Case



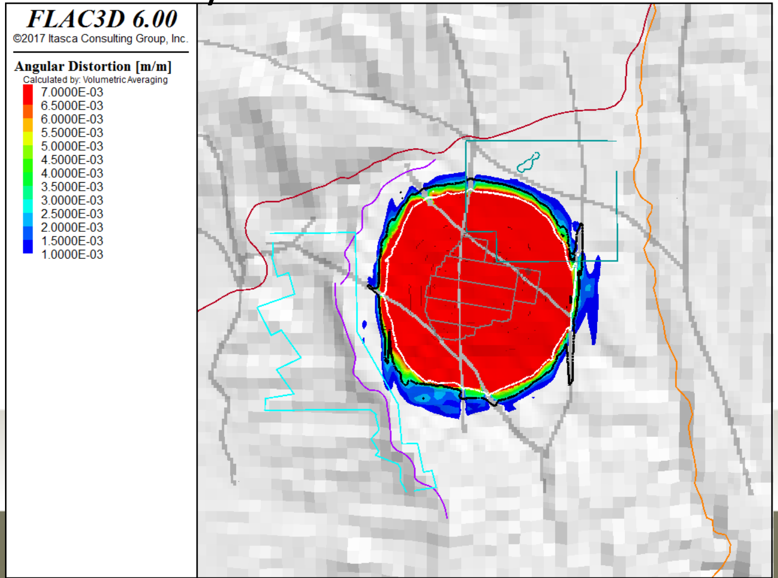
Sensitivity 5 – Max VSI=0.5



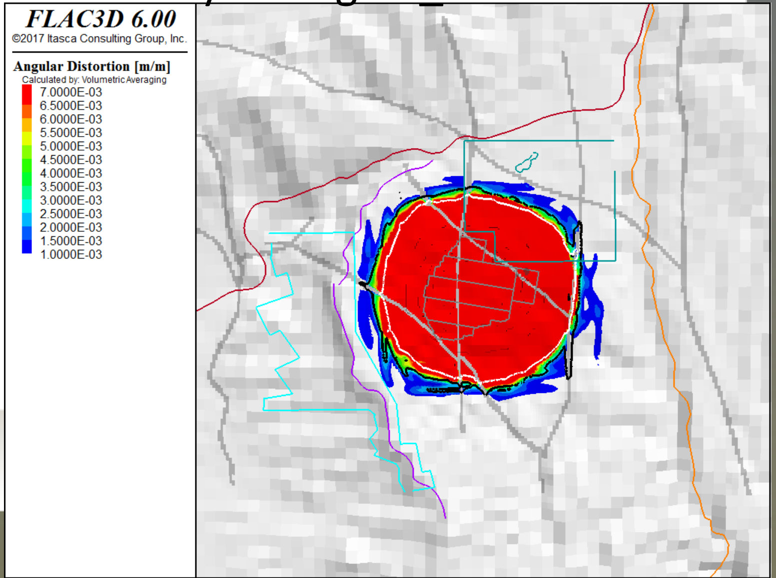
Sensitivity 6 – 125% K0



Sensitivity 7 – 75% K0



Sensitivity 8 – Sigma_H E-W



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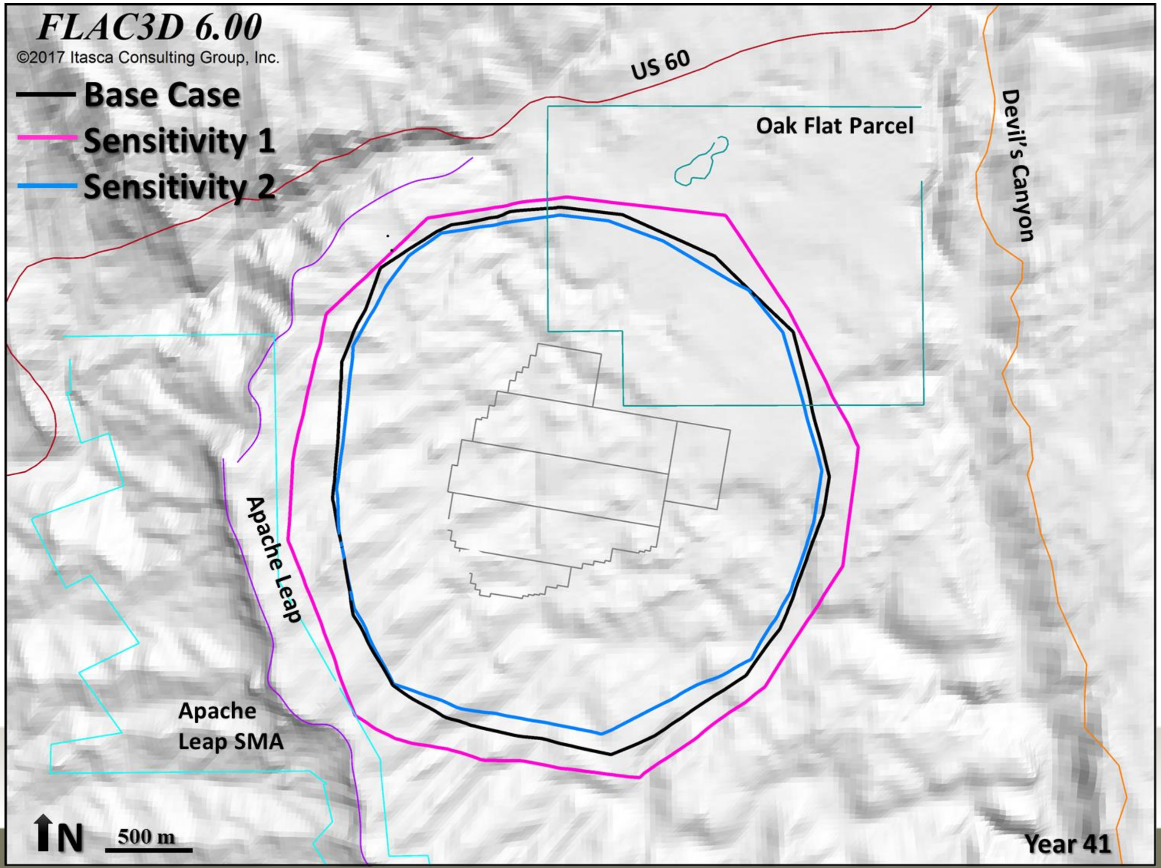
Break-through Timing and Crater Depth

Model name	Break-through timing	Crater Depth [m]
Base Case	Year 6	240
Original Strong	Year 6	340
Sensitivity 1	Year 7	240
Sensitivity 2	Year 6	240
Sensitivity 3	Year 7	240
Sensitivity 4	Year 6	280
Sensitivity 5	Year 6	260
Sensitivity 6	Year 7	240
Sensitivity 7	Year 6	240
Sensitivity 8	Year 6	240

Break-through timing in all cases happens between Year 6-7
Crater depth was affected by mesh resolution at depth (larger step increments)

Sensitivity to Rock Mass Global Strength

Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 1	**75%** σ_{cm}	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 2	**125%** σ_{cm}	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S



Weaker rock mass global strength extends the fracture limit farther out

Rock Mass Global Strength

- **How conservative are the base case and lower bound rock mass strengths examined?**
- We can understand the range in rock mass strength by performing a Monte Carlo analysis of σ_{cm}
  - Monte Carlo is a well-established technique for understanding rock mass strength distribution
  - Involves randomly sampling the input distributions of GSI and UCS to calculate a distribution of rock mass strength from the Hoek-Brown criterion
  - Example applications:
    - Hoek, Evert. "Reliability of Hoek-Brown estimates of rock mass properties and their impact on design." International Journal of Rock Mechanics and Mining Sciences 35.1 (1998): 63-68.
    - Li, A. J., et al. "Parametric Monte Carlo studies of rock slopes based on the Hoek–Brown failure criterion." Computers and Geotechnics 45 (2012): 11-18.
    - Sari, Mehmet, Celal Karpuz, and Can Ayday. "Estimating rock mass properties using Monte Carlo simulation: Ankara andesites." Computers & Geosciences 36.7 (2010): 959-969.

Rock Mass Global Strength: UCS Distribution

- UCS derived from Point Load data:
  - most complete intact strength data set (227 samples for Apache Leap Tuff)
  - need to multiply by 80% for scale effect

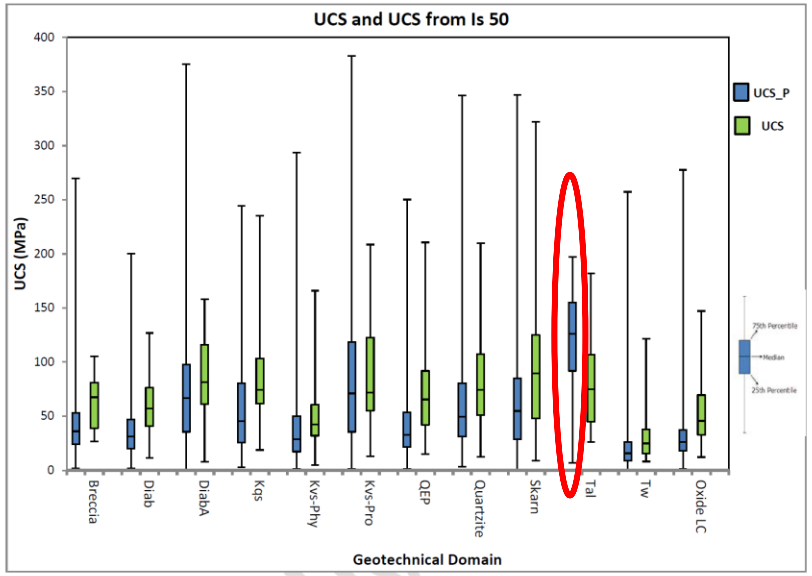
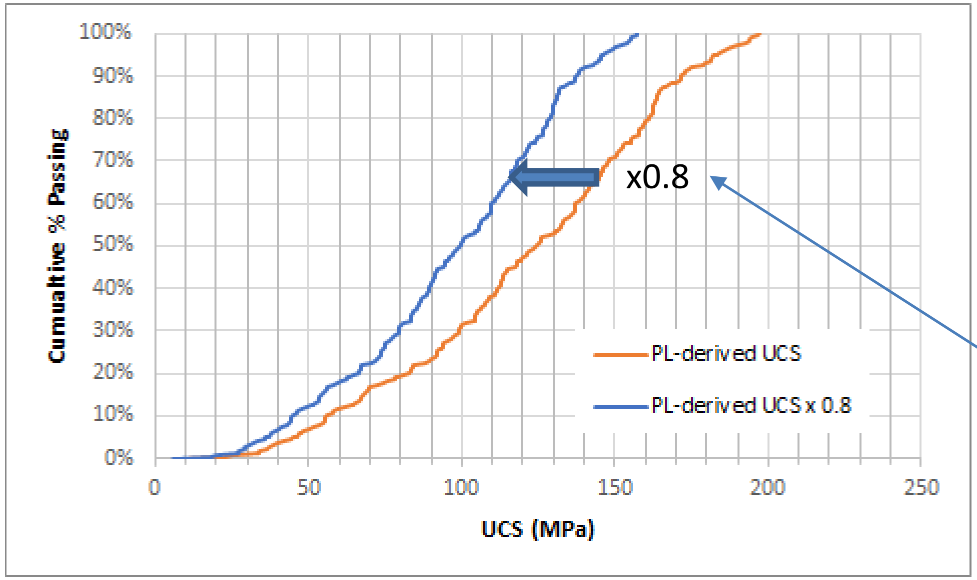
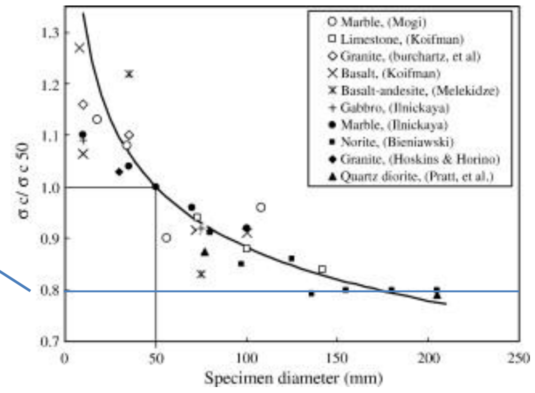


Figure 1-16 Point Loads Vs UCS for each geotechnical domains



Hoek and Brown (1980)



Rock Mass Global Strength: GSI Distribution

- The Geological Strength Index (GSI) was estimated based on block volume using the methodology proposed by Cai et al. (2004).
- Block volumes were estimated from core logging using both apparent spacing and the Joint Weighted Density methodology (Palmstrom, 2005).
  - They give very similar results
  - JWD-derived GSI used

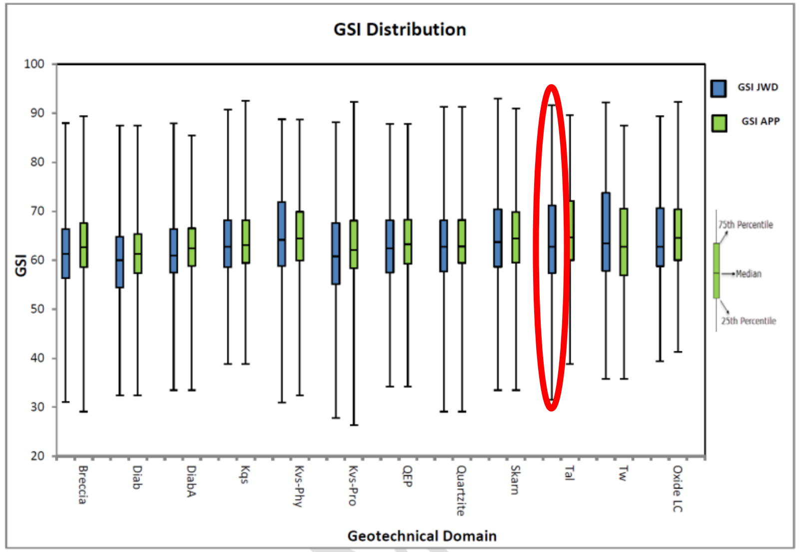
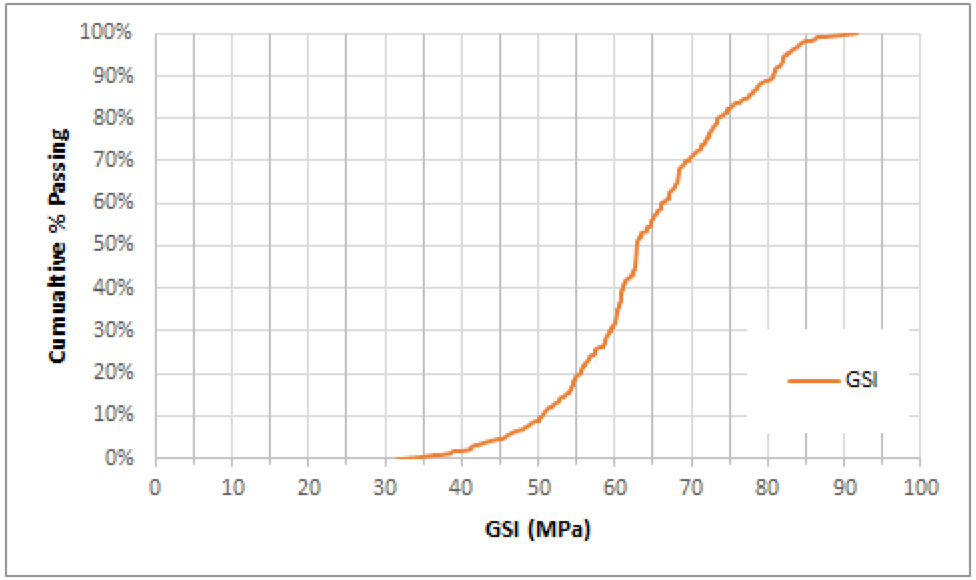


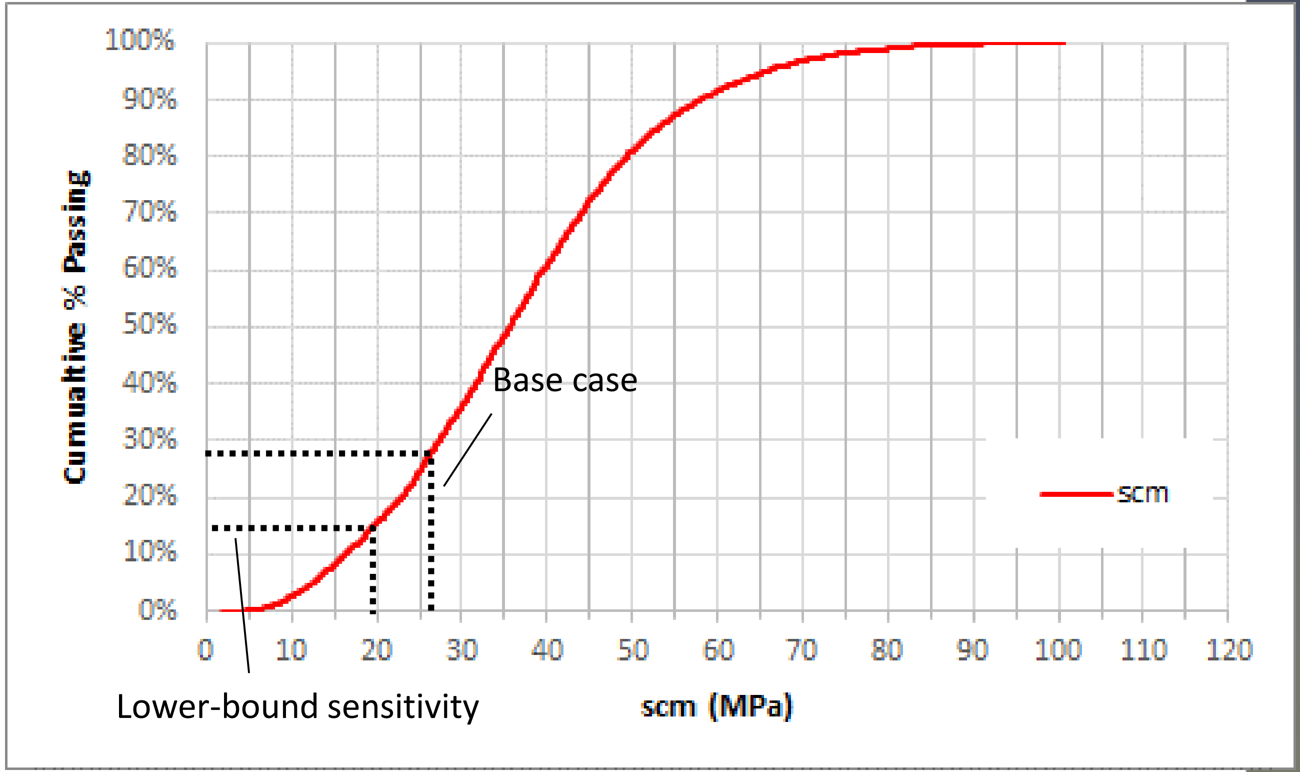
Figure 1-21 Distribution of GSI values for each geotechnical domain (block volume estimated from apparent joint spacing)



Rock Mass Strength: Monte Carlo Analysis

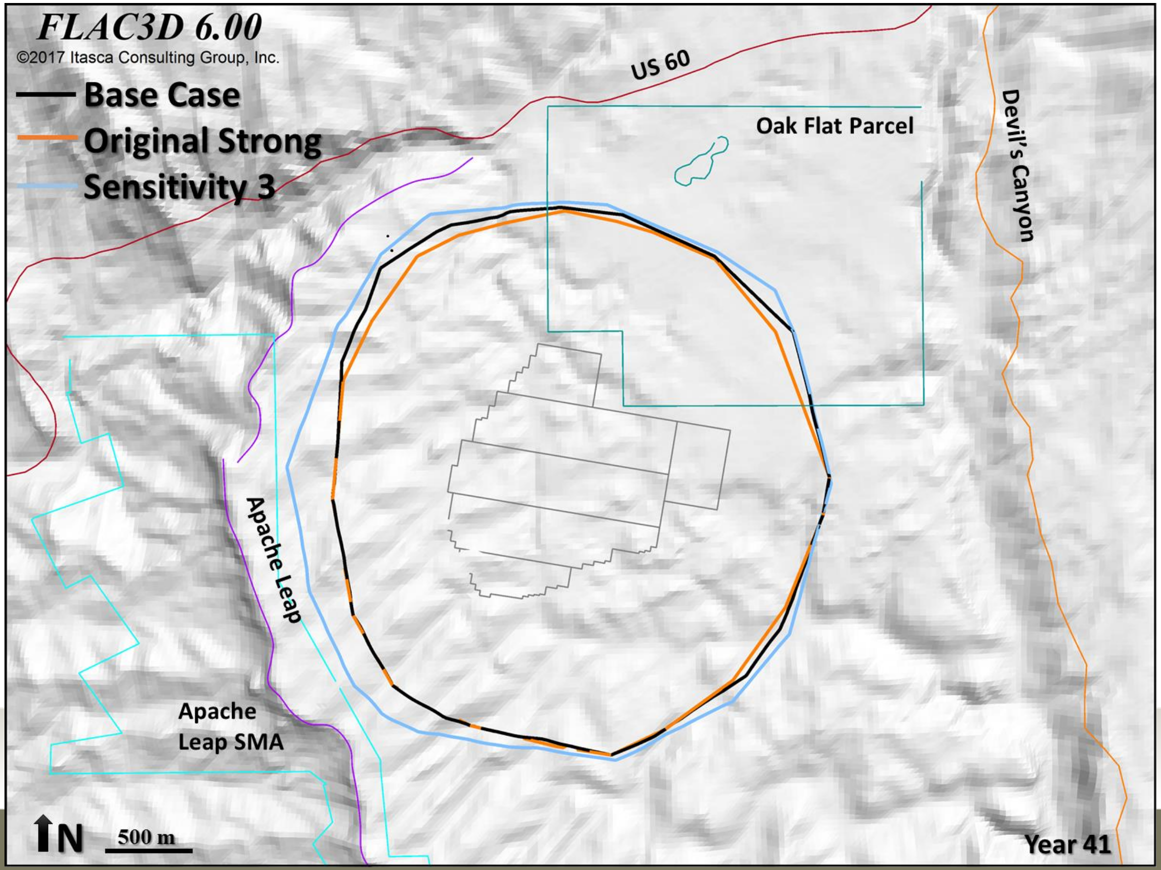
- UCS and GSI distributions sampled randomly and independently 5000 times (assumes no correlation between UCS and GSI)
- Sigcm (rock mass strength) calculated from each UCS-GSI pair
- Resulting distribution in sigcm reflects variability in rock mass strength at a much smaller scale than the cave
- Representative "controlling" strength in heterogenous materials is typically the 30-40th percentile (Pierce, 2010; Lorig et al., 2018)
- **Base case: 27th percentile (Sigcm=26.0 MPa)**
- **Lower-bound sensitivity: 15th percentile (Sigcm 19.5 MPa)**
  - **Very conservative**

Estimated Range in Rock Mass Strength (sigcm) for Apache Leap Tuff



Sensitivity to Fault Strength

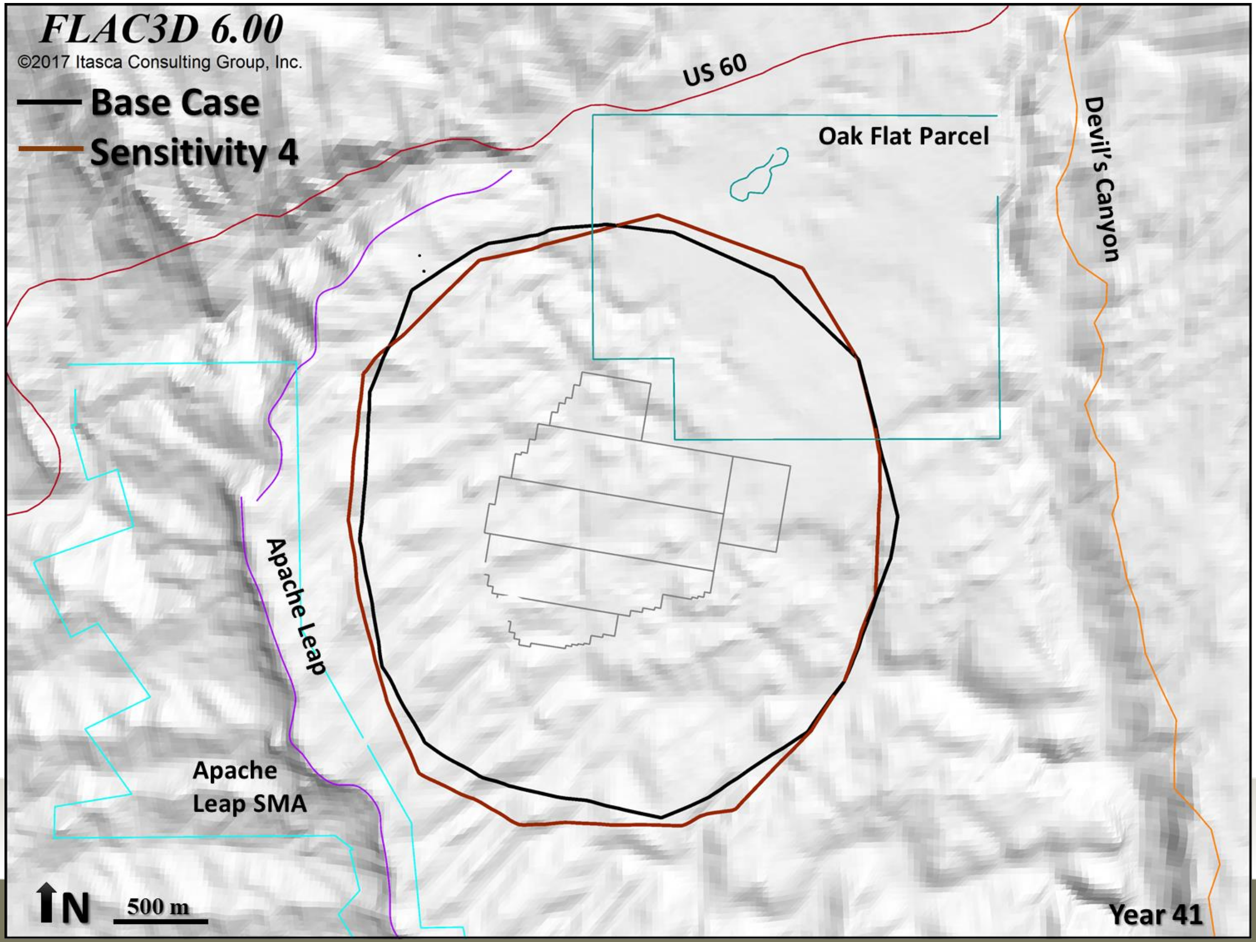
Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Original Strong	100%	**Strong Case**	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 3	100%	**Weak Case**	Base Case	0.67 (40% porosity)	Base Case	N-S



Fault strength has small effect on fracture limit extension

Sensitivity to Rock Mass Residual Strength

Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 4	100%	Base Case	**Sensitivity**	0.67 (40% porosity)	Base Case	N-S



Lower rock mass residual strength slightly reduces the fracture limit extension

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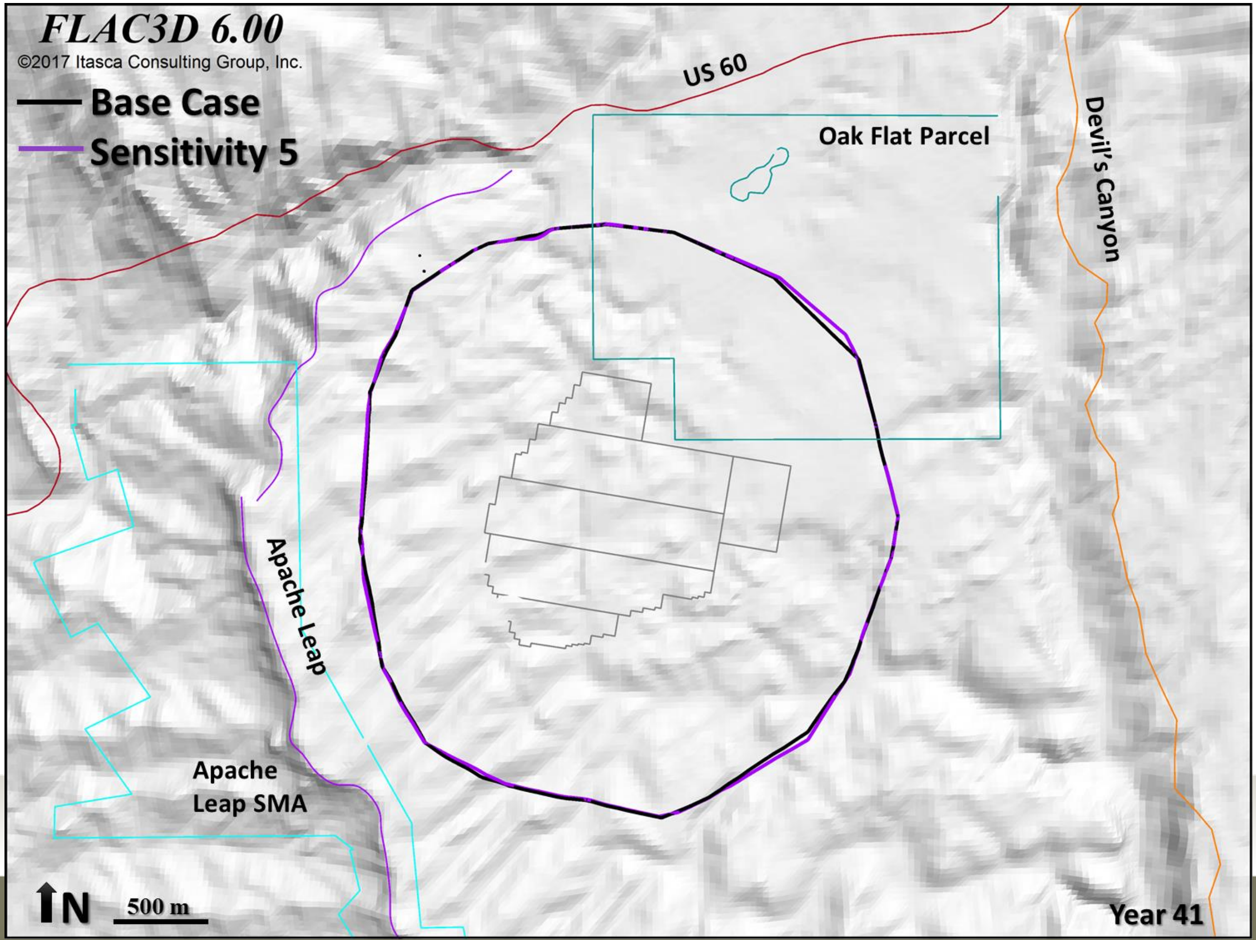
Sensitivity to Maximum VSI (Max. Porosity)

Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 5	100%	Base Case	Base Case	**0.5 (30% porosity)**	Base Case	N-S



Maximum VSI does not affect fracture limit (sensitive to draw schedule)

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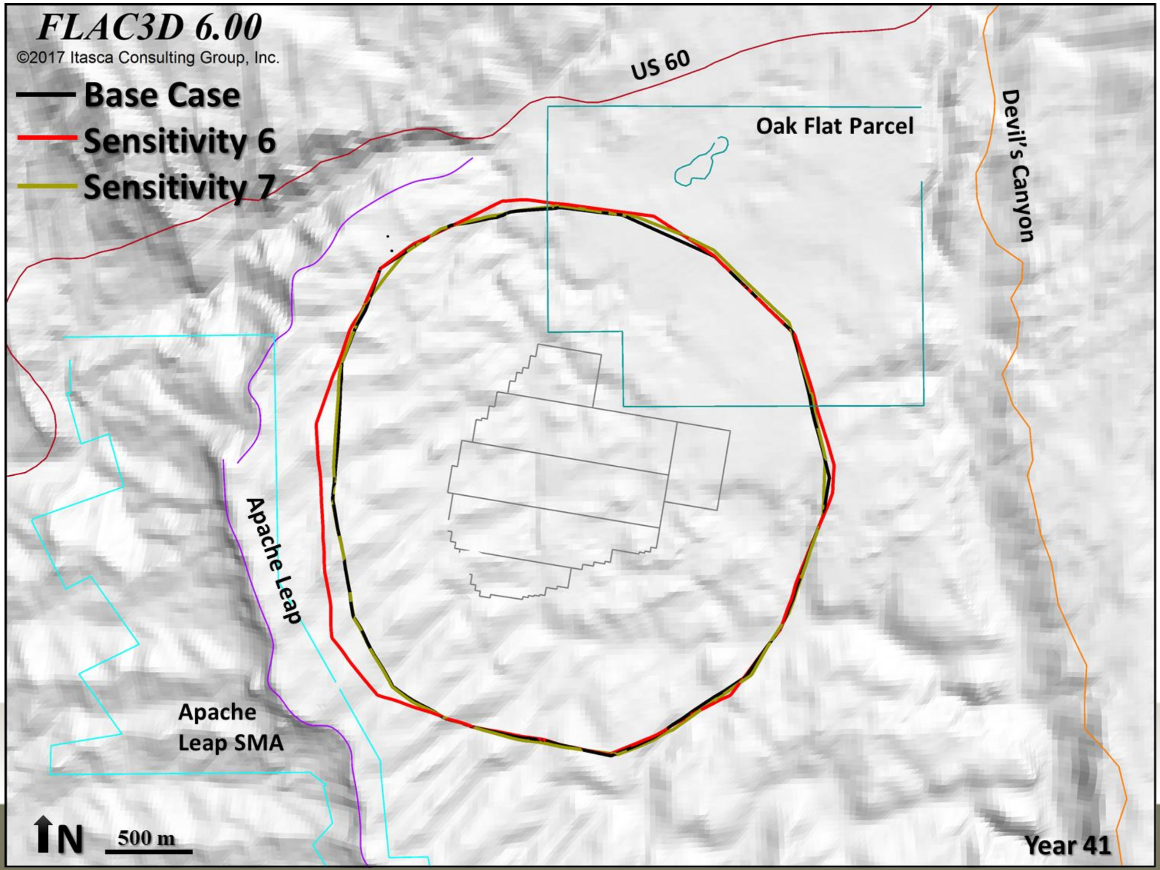
Sensitivity to In-situ Stress Magnitude

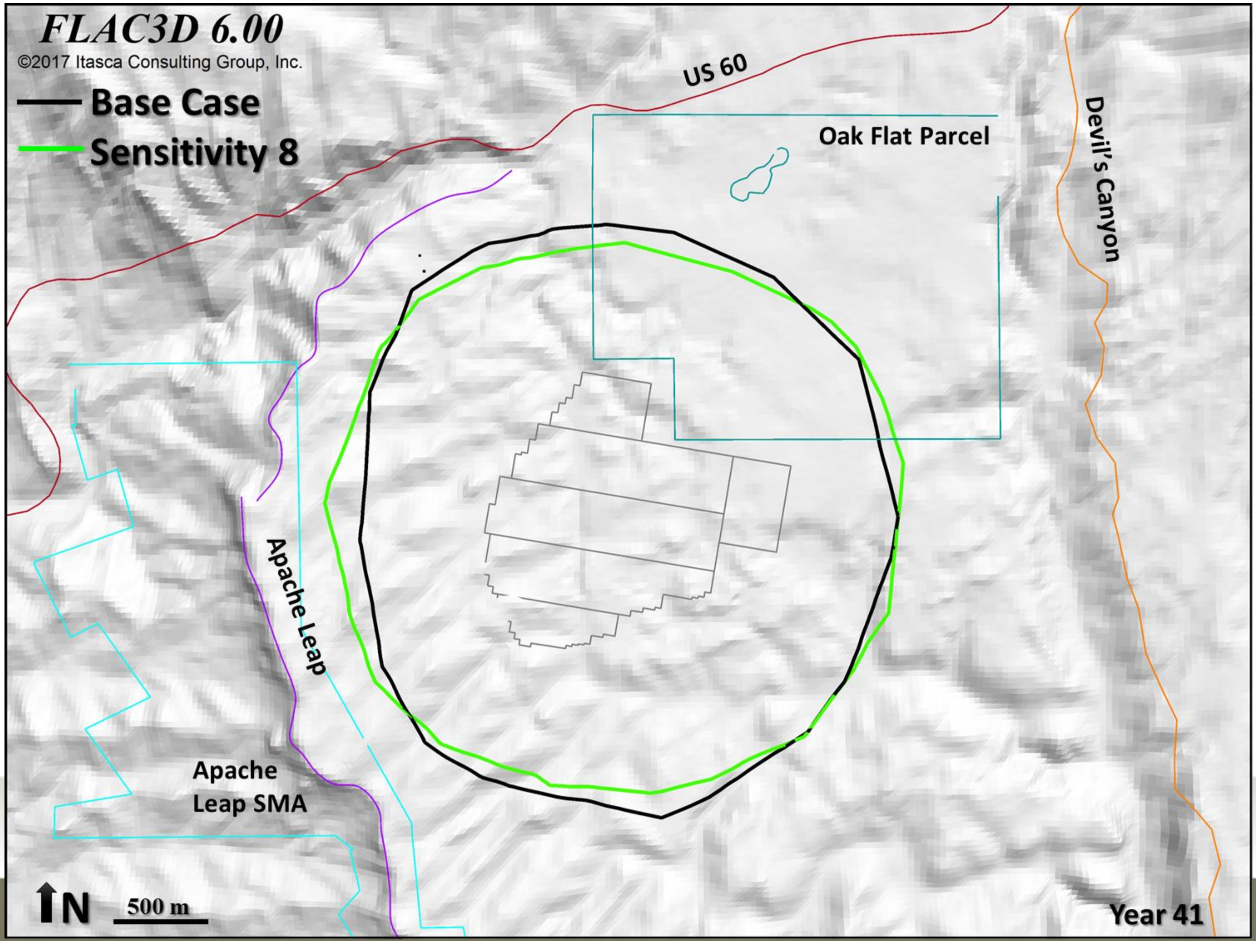
Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 6	100%	Base Case	Base Case	0.67 (40% porosity)	**125% K0**	N-S
Sensitivity 7	100%	Base Case	Base Case	0.67 (40% porosity)	**75% K0**	N-S



A variation of ±25% of in-situ horizontal stress magnitude has minimal effect on fracture limit

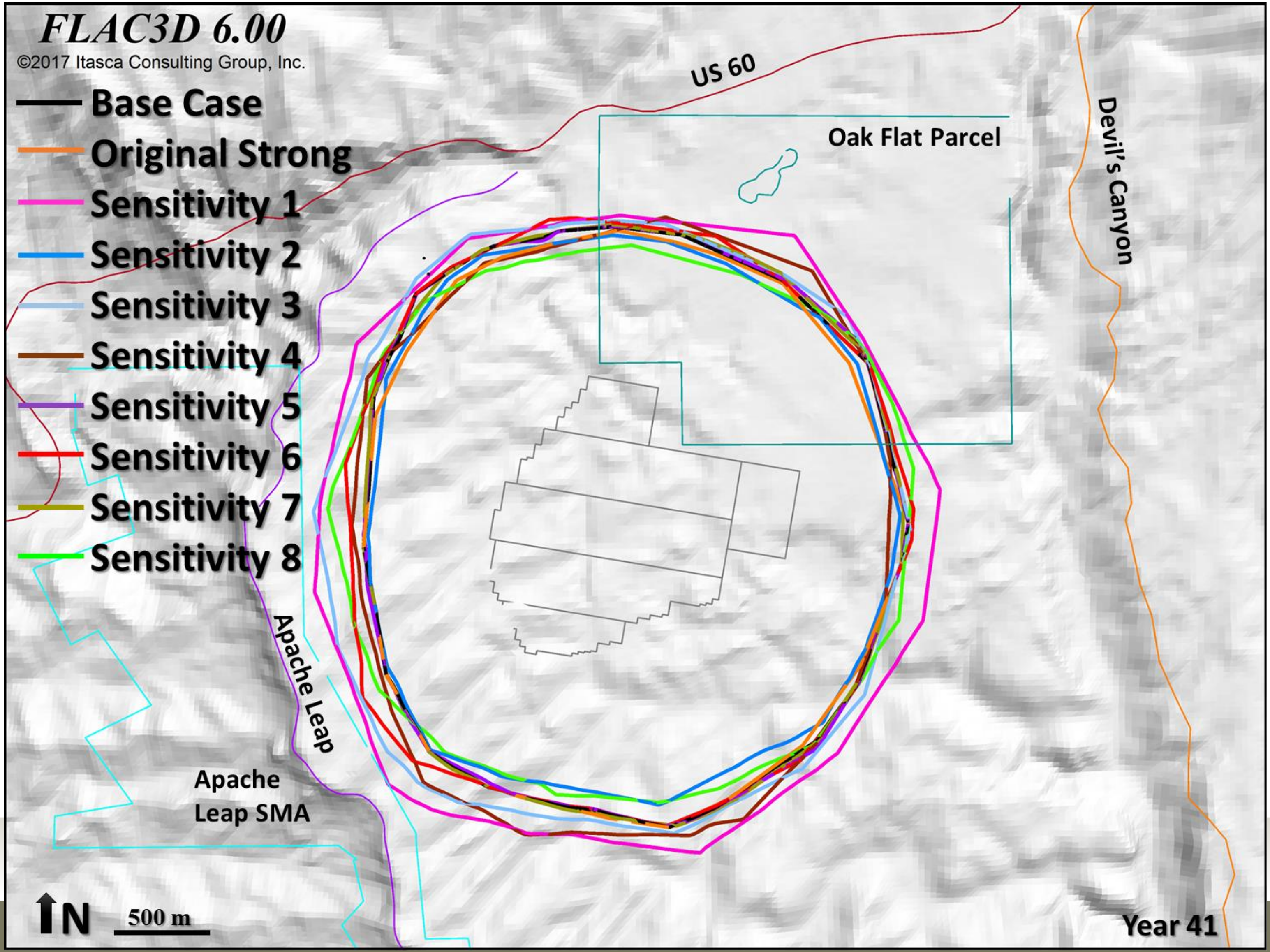
Sensitivity to Sigma_H Direction

Model name	Rock Global Strength	Fault Properties	Residual Strength	Max. VSI	In-situ Stress	Sigma_H direction
Base Case	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	N-S
Sensitivity 8	100%	Base Case	Base Case	0.67 (40% porosity)	Base Case	**E-W**



A 90° rotation on in-situ stress direction causes a rotation on the long axis of the fracture limit (E-W)

All Sensitivities



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Observations

The sensitivity study revealed:

- **In all cases, no damage to the Apache Leap, Devil's Canyon or to the serviceability of Highway US-60 is expected**
- Fault strength has small effect on fracture limit extension
- Weaker rock mass global strength slightly extends the fracture limit
- Lower rock mass residual strength slightly reduces the fracture limit extension
- Maximum VSI does not affect fracture limit (sensitive to draw schedule)
- A variation of ±25% of in-situ horizontal stress magnitude has minimal effect on fracture limit
- A 90° rotation on in-situ stress direction causes a rotation on the long axis of the fracture limit (E-W)
- Little variability in cave break-through timing (Year 6-7) is observed between cases
- Variability in crater depth is partly due to mesh refinement at deeper levels
- In general, the fracture limits are mainly dependent on the extraction level geometry, depth and draw schedule