



Simulation Engineering Community Track

Geotechnic & Bulk Material

Date & Time of the session

DS Contact:

09:00-09:25, December 6

► Speaker name

Patrick Kwang Chun

► Speaker Title

From LiDAR scanning to Geotechnical Stability Analysis of the Kartchner Caverns in Arizona with 3D visualization computing solution

► Speaker Bio

Dr Chun works as a research engineer at the University of Arizona since 2016. His current research is numerical modeling of mining related rock mechanics problems such as slope stability analysis, modeling of subcritical crack growth and rock damage simulation. His specialties are mining geomechanics, rock fracture mechanics, numerical modeling & simulation of petroleum related rock mechanics such as hydraulic fracture modeling, thermal cracking, wellbore stability. In the past 5 years, he worked as a visiting research associate at Baker Hughes Dhahran research center in Saudi Arabia. He holds PhD degree in Petroleum Engineering from Texas A&M University, College Station, Texas, USA.

► Session description (for who, what)



3DEXPERIENCE®

From LiDAR scanning to Geotechnical
Stability Analysis of the Kartchner
Caverns in Arizona with
3D visualization computing solution

Patrick Chun, PhD
The University of Arizona

Presentation outline

- Introduction
- LiDAR
- Kartchner Caverns
- Point clouds data acquisition and processing for 3D meshing
- 3D Finite element analysis (Abaqus)
- 3D Data visualization (ParaView)
- Conclusion

Introduction

Importance of underground structures

- ❑ Structures built beneath the earth's surface
- ❑ Play important role in energy sustainability, storage, production...
- ❑ Examples: (i) Tunnels
 - (ii) Underground and surface mines
 - (iii) Caverns and openings
- ❑ 3D stability analysis is the key for stability and safety



Introduction

Methodology for 3D stability analysis (Numerical + Geomechanics)

- ❑ Numerical analysis – FEM, DEM, BEM, etc
- ❑ Geomechanics techniques – Remote sensing technology
 - Remote sensing – LiDAR, drone, aircraft, etc
 - Advantages – ease of use, high accuracy
 - Difficulties – conversion to 3D FEM model when complex surfaces exist in geological body



Research objectives

- Propose new integration process from LiDAR scanning to 3D FEA and 3D visualization solution
- Develop new algorithm to reconstruct 3D numerical model from underground structures containing complex surface geometry
- Present new 3D visualization techniques to show 3D finite element simulation results using scientific computing solution

Overview of workflow

by chart

Step 1

3D scanning
& acquisition
of points cloud

Step 2

3D surface model
(MeshLab)

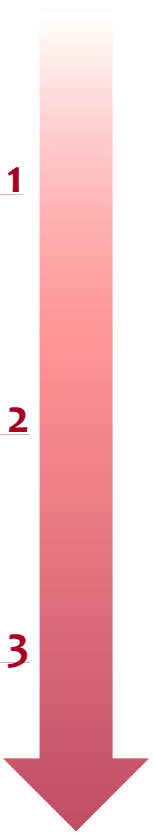
3D solid model
(Rhinoceros 5)

FEM model
computation
(Abaqus 2017)

Step 3

FEM model
results
(Abaqus 2017)

3D Visualization
of FEM results
(Para View)



LiDAR (Light Detection And Ranging)

Definition and Usage



- ❑ Remote sensing technology
- ❑ Acquire 3D topographic information of underground structures
- ❑ Used for ensuring underground stability and safety
- ❑ Used in numerous fields (earth sciences, land surveying, structures...)

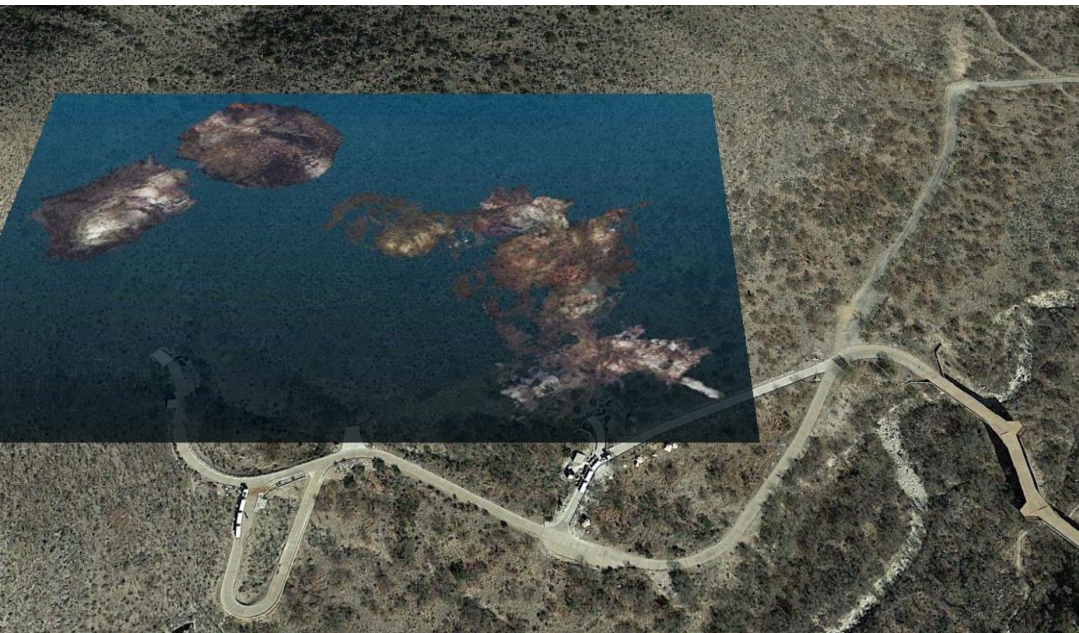
LiDAR (Light Detection And Ranging)

Scanning output → Points clouds

- ❑ A collection of data points produced by 3D scanners
- ❑ Used to create 3D meshes and 3D modeling
- ❑ Points cloud consisting of the following:
 - Location – X,Y,Z coordinates of points on reflective surfaces
 - Intensity – surface reflectivity of the laser beam

Kartchner Caverns

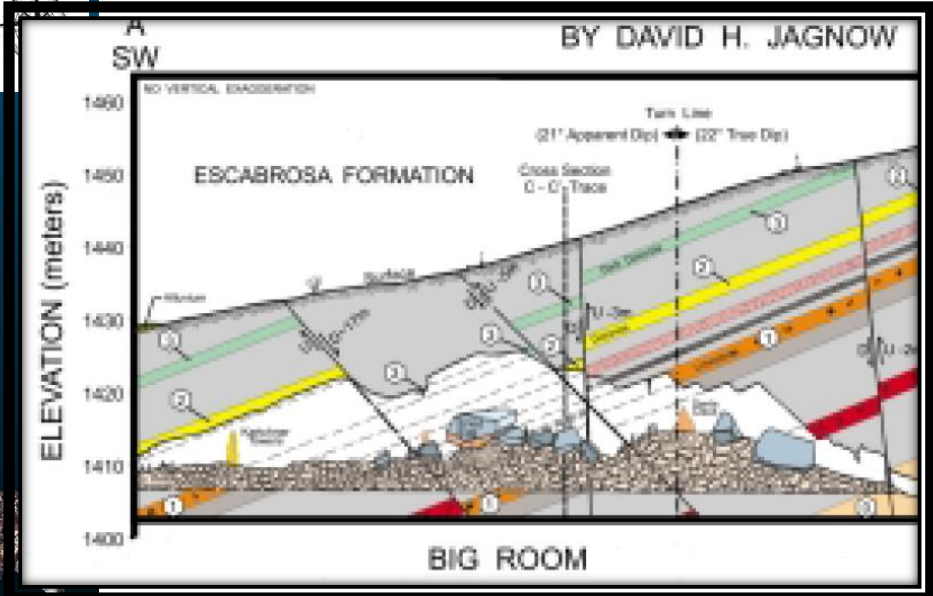
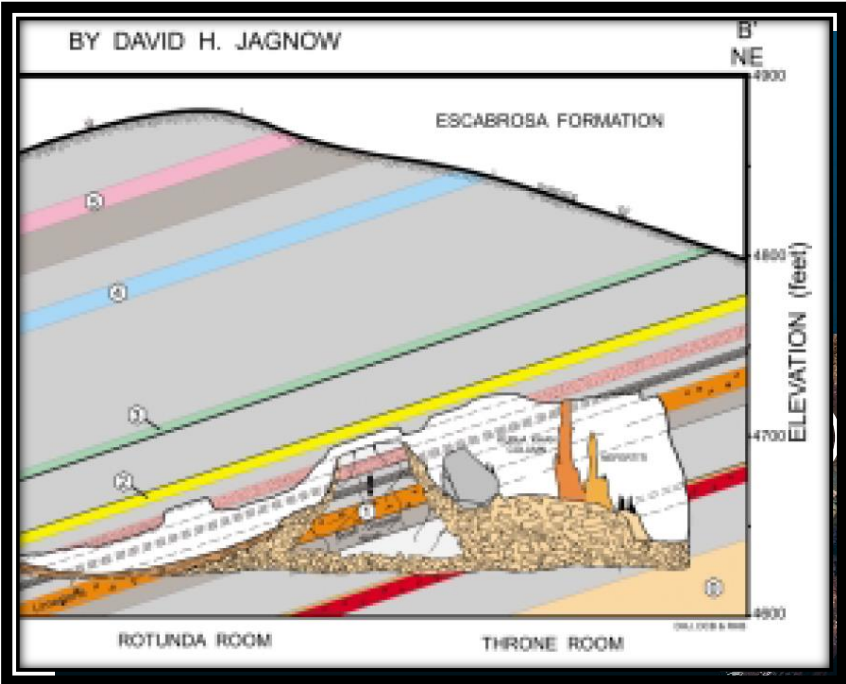
General information



- Located in southeastern Arizona, USA
(50 min by drive from Tucson)
- Discovered in 1974
- Escabrosa limestone formation
- Opened to public since 2003

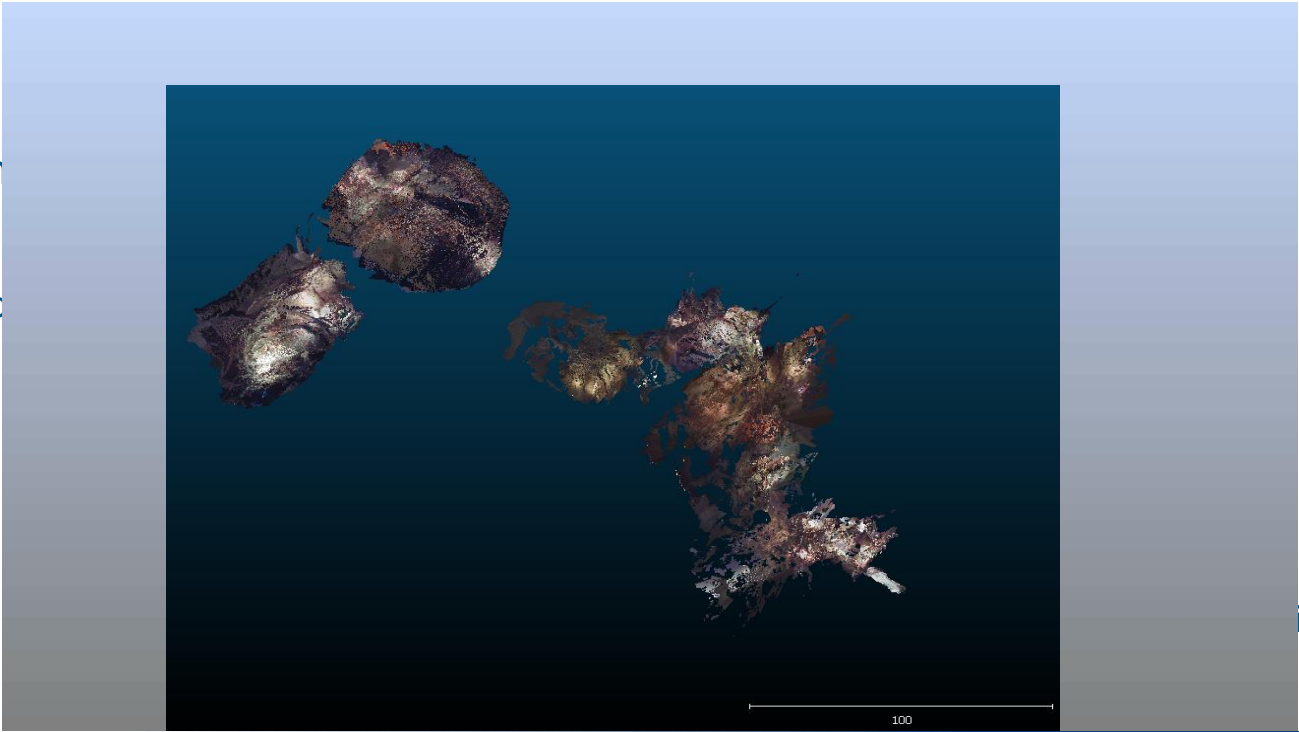
Kartchner Caverns

3 Major caves (Big, Throne, Rotunda room)



LiDAR scanning at three caves

- Rotunda and Throne
- 3 scans each
 - 82 million points/ ro

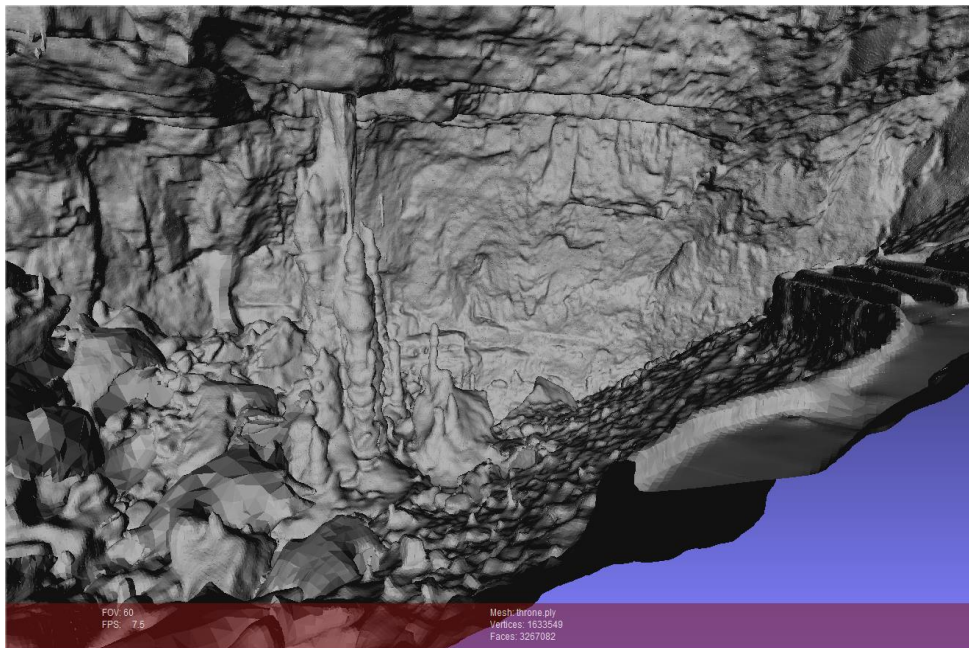


S
ion points

3D Surface Mesh

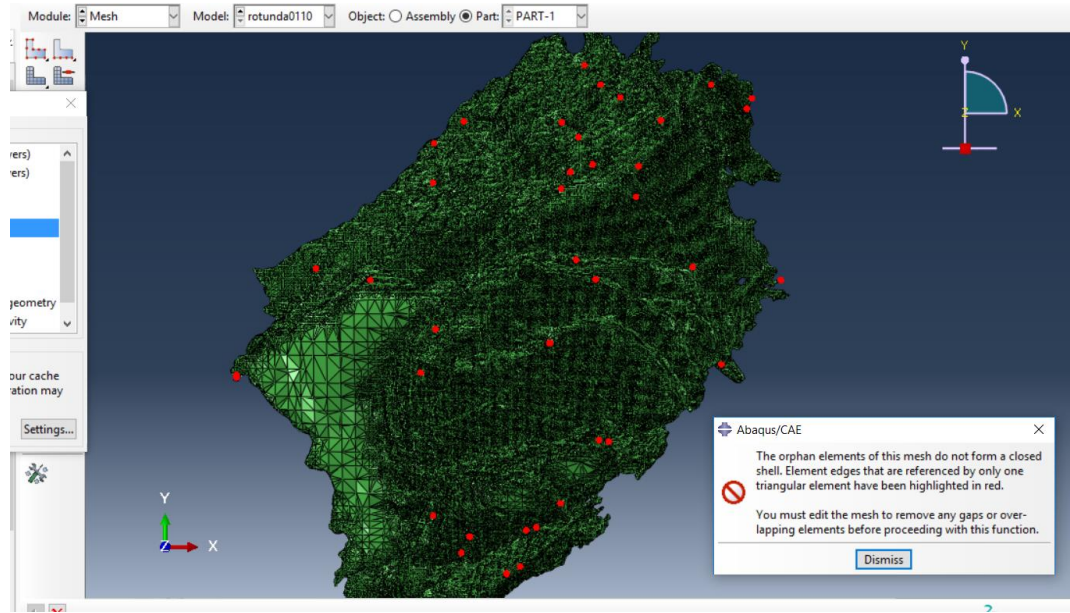
Surface reconstruction in Meshlab

- ❑ Create 3D unstructured triangular meshes
- ❑ Detailed 3D geometry representation
- ❑ Many small faces in highly detailed areas
- ❑ Mesh inconsistencies should be reconciled



3D Mesh repair

How to repair



❑ Mesh inconsistencies need to be repaired

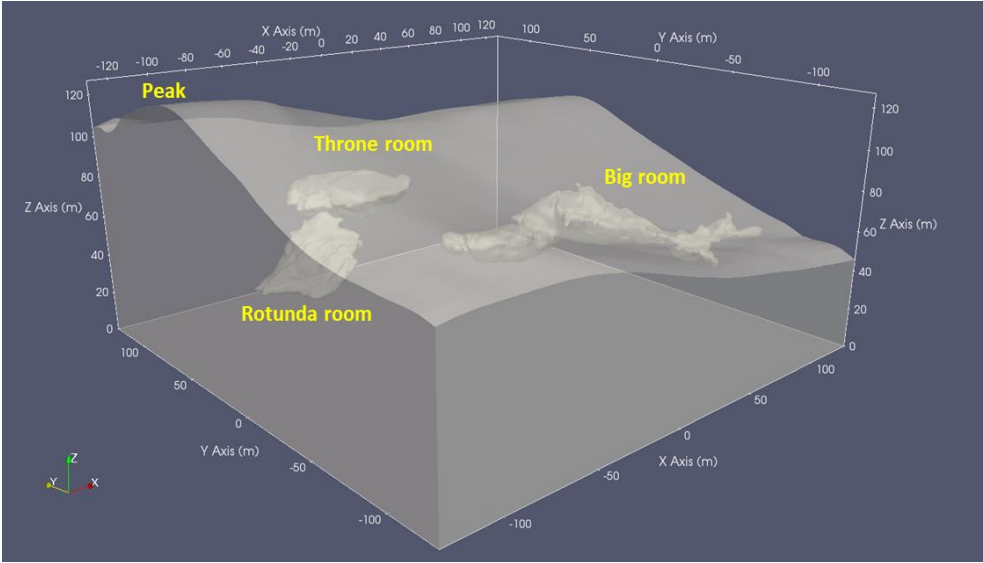
➤ automatic process by scripting

➤ manual process by hand

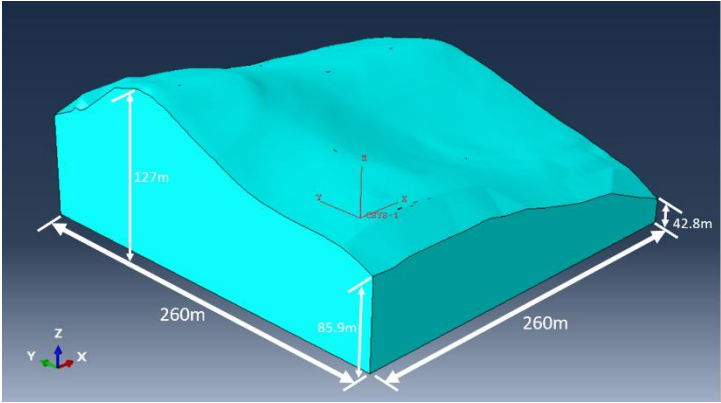
❑ After mesh repair,
convert to 3D solid model

3D Finite element model

Kartchner Caverns 3D model

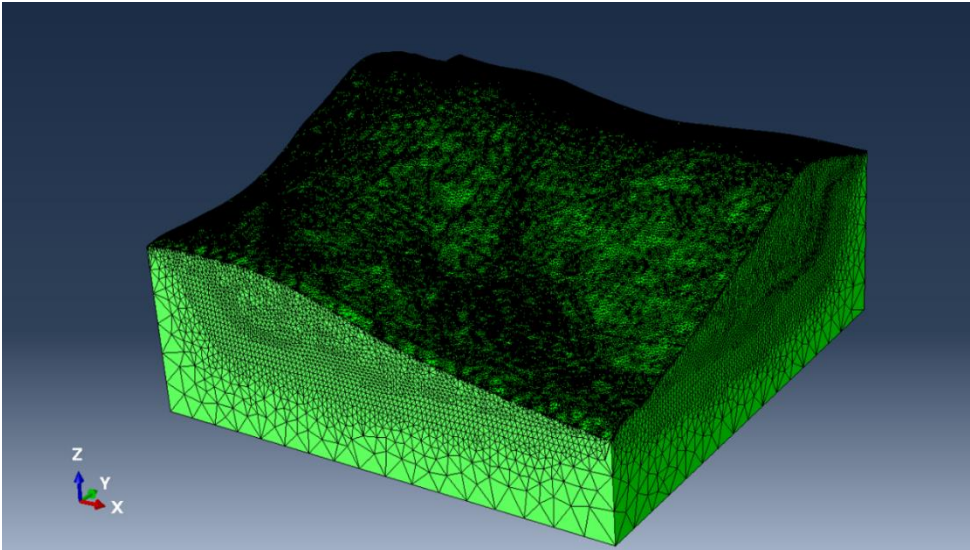


<ParaView ver. 5.2.0>



<Abaqus 2017>

3D Finite element Analysis



- ❖ tetrahedron volume elements
- ❖ 89 million elements
- ❖ mesh refinement near excavations
- ❖ run on HPC workstation

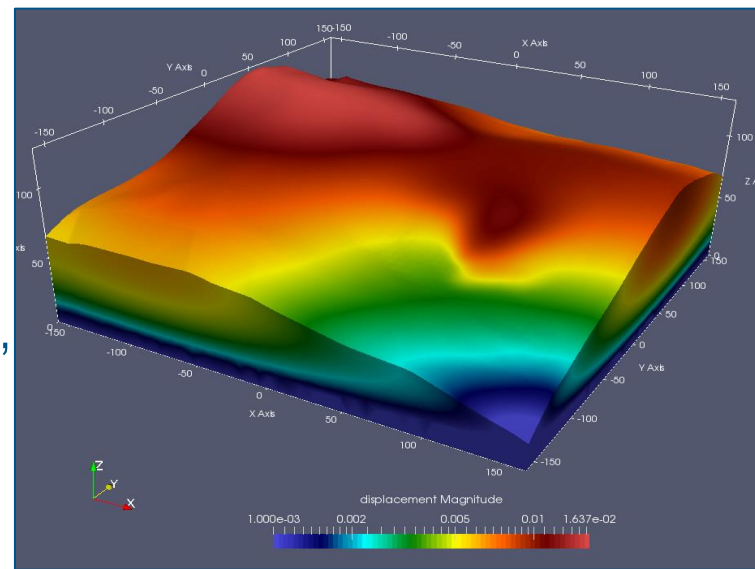
Material parameters	Symbol	value
Young's modulus	E (GPa)	8.8
Poisson's ratio	ν	0.32
Density of the rock	ρ (kg/m ³)	2670

3D Scientific Visualization

Intro of ParaView

ParaView

- ❑ Popular scientific visualization toolkit
- ❑ Handle different types of large datasets
- ❑ Incorporation of transforming raw data using ‘filters’
- ❑ Scripting interface using Python



3D Visualization

Abaqus ODB to ParaView VTK file

computing solution

ParaView

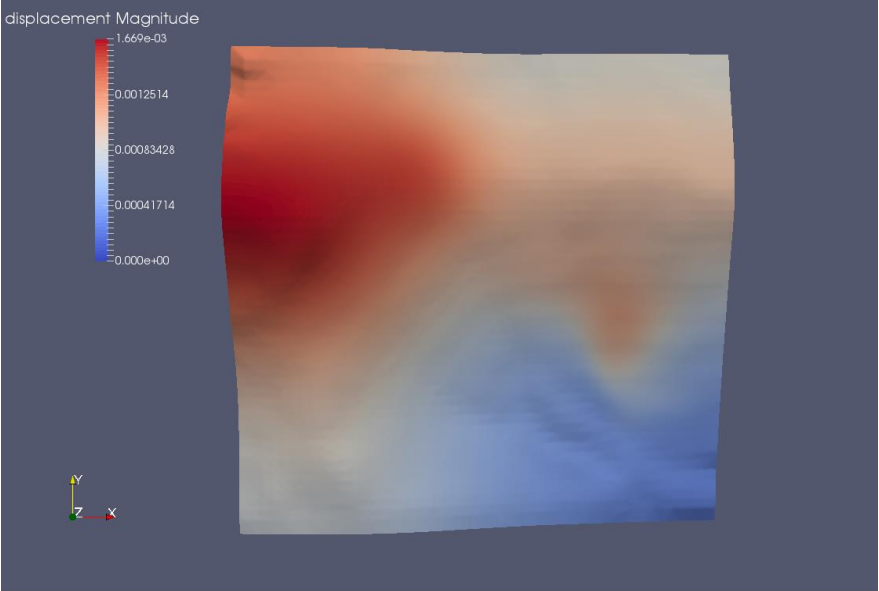
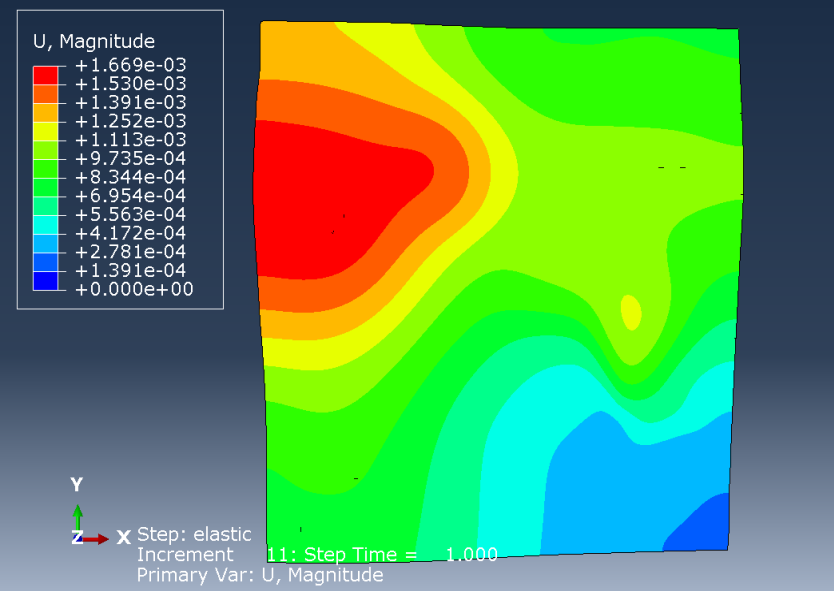
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0 10 20 30 40 50 60 70 80 90 100 110
1 INPPATH = 'C:/Temp/123117Kartchner3_box.inp'
2 ODBPATH = 'C:/Temp/123117Kartchner3_box.odb'
3 OUTPATH = 'C:/Temp/123117Kartchner3_box.vtu'
4
5 from odbAccess import openOdb
6 from abaqusConstants import *
7
8
9 class DataSet:
10     def __init__(self):
11         self.nodes = {}
12         self.elements = {}
13         self.stress = {}
14         self.displacement = {}
15
16     def insertNode(self, nid, x, y, z):
17         self.nodes[int(nid)] = [float(x), float(y), float(z)]
18
19     def insertTetr(self, eid, n0, n1, n2, n3):
20         self.elements[int(eid)] = [int(n0), int(n1), int(n2), int(n3)]
21
22     def insertStress(self, eid, mises, s11, s22, s33,
23                     self.stress[int(eid)] = [float(mises), float(s11), float(s22), float(s33), float(s12), float(s13), float(s23)]
24
25     def insertDisplacement(self, nid, ux, uy, uz):
26         self.displacement[int(nid)] = [float(ux), float(uy), float(uz)]
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123 strss = myOdb.steps[stepName].frames[-1].fieldOutputs['S'].getSubset(position=CENTROID)
124 disp = myOdb.steps[stepName].frames[-1].fieldOutputs['U']
125
126 for srs in strss.values:
127     eid = srs.elementLabel
128     mises = srs.mises
129     sxx = srs.data[0]
130     syy = srs.data[1]
131     szz = srs.data[2]
132     sxy = srs.data[3]
133     sxz = srs.data[4]
134     syz = srs.data[5]
135     data.insertStress(eid, float(mises), float(sxx), float(syy), float(szz), float(sxy), float(sxz), float(syz))
136
137 for disp in disp.values:
138     nid = disp.nodeLabel
139     ux = disp.data[0]
140     uy = disp.data[1]
141     uz = disp.data[2]
142     data.insertDisplacement(nid, ux, uy, uz)
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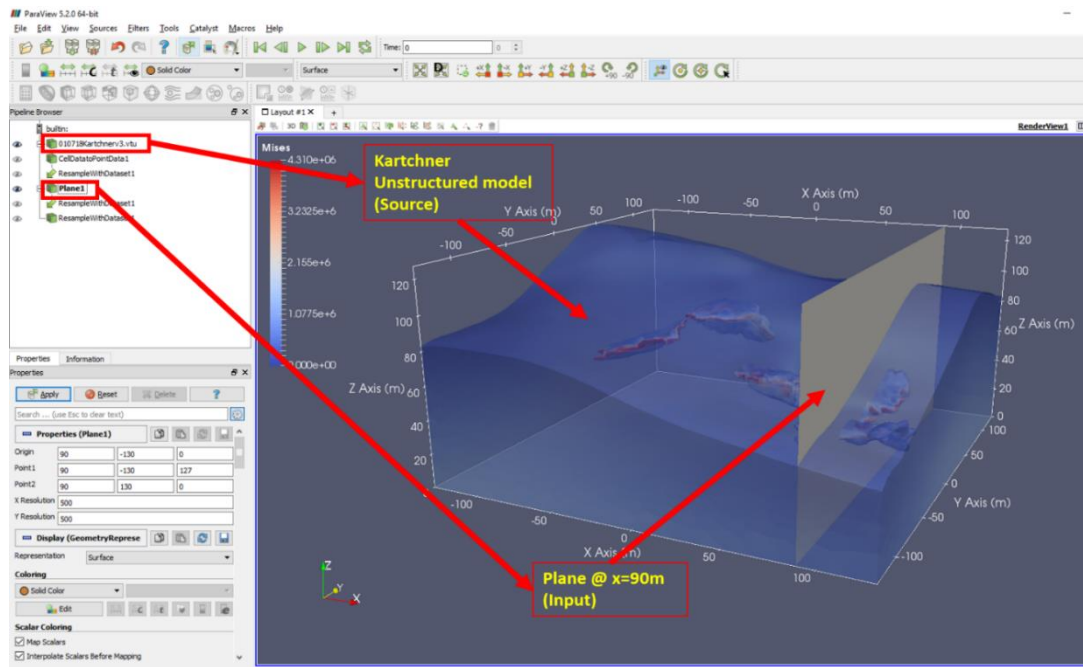
Finite element simulation results

Displacement contour



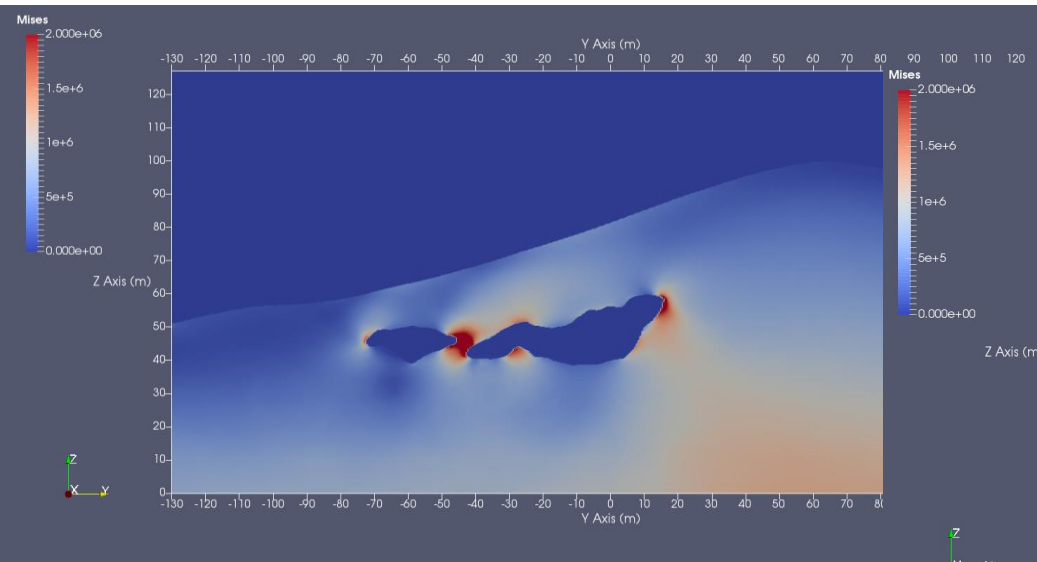
Finite element simulation results

Using 'Resample with Dataset' filter

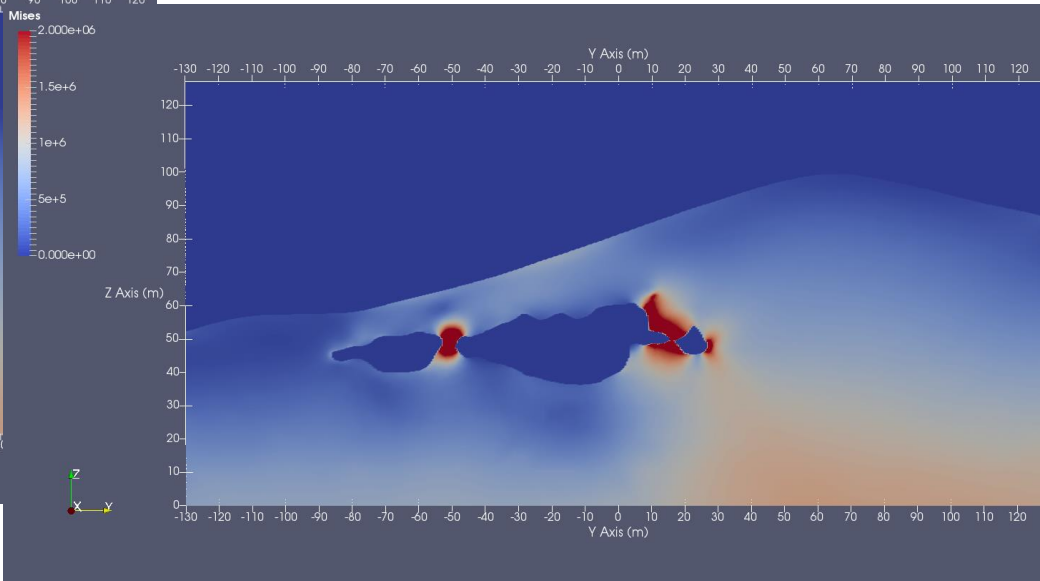


Finite element simulation results

Cross section view at Big Room



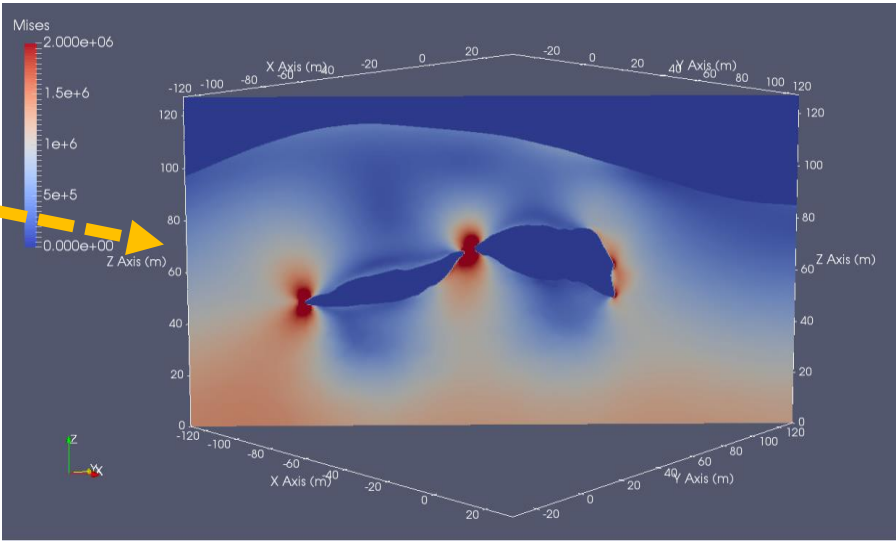
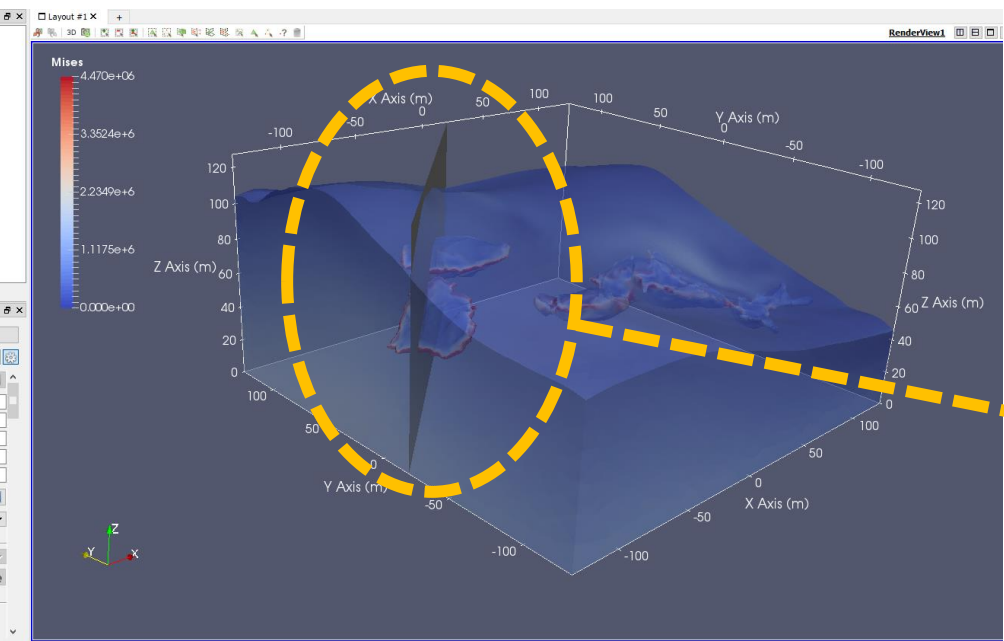
(Plane@ x=90m)



(Plane@ x=80m)

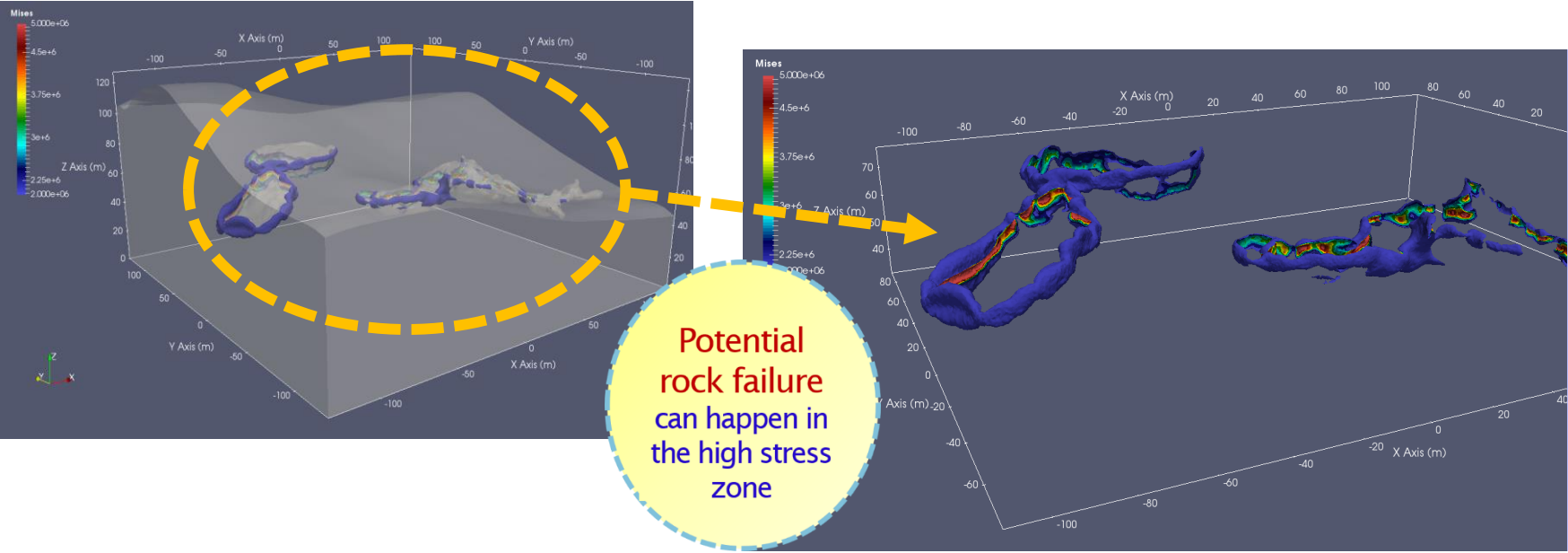
Finite element simulation results

Cross section view at Throne & Rotunda Room



Finite element simulation results

Iso surfaces representing high stress zone



Conclusion

- This paper proposes a comprehensive approach integrating from LiDAR scanning to 3D FEM analysis for complex surface and underground excavations
- The proposed method has been implemented in a very efficient way that allows the transformation into 3D numerical model of Kartchner Caverns from LiDAR point clouds
- Geotechnical stability analysis was conducted to demonstrate the effectiveness of merging LiDAR technology, 3D FEM simulation and 3D scientific visualization
- FEM result shows that the proposed approach can successfully estimate the stability of the excavated underground structures

Acknowledgement

- This work was supported by the National Science Foundation under NSF Award No.1332765 with the project title
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for Long-Term Rock Behavior”

Thank you

Q&A



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Specialties : Computational rock mechanics, geomechanics

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