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Printed September 2015

Construction of Hexahedral Elements Mesh Capturing Realistic Geometries of Bayou Choctaw SPR Site

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Prepared by
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Construction of Hexahedral Elements Mesh Capturing Realistic Geometries of Bayou Choctaw SPR Site

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Abstract

The three-dimensional finite element mesh capturing realistic geometries of Bayou Choctaw site has been constructed using the sonar and seismic survey data obtained from the field. The mesh is consisting of hexahedral elements because the salt constitutive model is coded using hexahedral elements. Various ideas and techniques to construct finite element mesh capturing artificially and naturally formed geometries are provided. The techniques to reduce the number of elements as much as possible to save on computer run time with maintaining the computational accuracy is also introduced. The steps and methodologies could be applied to construct the meshes of Big Hill, Bryan Mound, and West Hackberry strategic petroleum reserve sites. The methodology could be applied to the complicated shape masses for not only various civil and geological structures but also biological applications such as artificial limbs.

ACKNOWLEDGMENTS

This research is funded by SPR programs administered by the Office of Fossil Energy (FE) of the U.S. Department of Energy.

The authors would like to thank the members of Cubit-Help, particularly Corey D. Ernst, Robert A. Kerr, Byron W. Hanks, Brett W. Clark, Matthew L. Staten, Clinton J. Stimpson, and Steven J. Owen for providing technical supports and some general information about Cubit. Courtney G. Herrick and Steven R. Sobolik of Sandia provided technical reviews. David J. Borns and Moo Y. Lee of Sandia managers supported this work. As always, the support of Diane Willard, Wayne Elias of DOE is greatly appreciated. Paul Malphurs of DOE also is greatly appreciated, as is his comprehensive review of this report. This report has been improved by these individuals.

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NOMENCLATURE

3D	Three-Dimensional
BC	Bayou Choctaw
CGZ	Clay and Gypsum Zone
DOE	Department of Energy
EFF	Extended File Format
E-W	East-West
FE	Finite Element
GAZ	Gypsum-Anhydrite Zone
ID	Identification
M-D	Multi-Mechanism Deformation
MMB	Million Barrels
MVS	Mining Visualization System
N-S	North-South
PLC	Power Law Creep
Sandia	Sandia National Laboratories
SPR	Strategic Petroleum Reserve
TBM	Tunnel Boring Machine
UTP	Union Texas Petroleum

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1. INTRODUCTION

Sandia National Laboratories (hereafter ‘Sandia’) uses large-scale, three-dimensional computational models to model the geomechanical behavior of underground storage facilities consisting of solution-mined caverns in a salt dome. It is not easy to realize the naturally formed cavern, salt dome, and opening in the rocks into some regular geometrical shapes. It is harder to convert the geometries into the meshed mass consisting of only hexahedral finite elements commonly used in these computational models. The opening excavated using a machine such as tunnel boring machine (TBM) could have a regular shape. However, the geometry of a cavern leached by solution mining in the salt will be irregular. The irregularity of the shape will be compounded if a salt fall occurs within the cavern. The geometries of the salt dome containing caverns and the caprock over the salt dome are also naturally formed, and therefore irregular and complex in shape. This report describes how to realize the geological mass combining artificially and naturally formed geometries into a geomechanical model.

The U.S. Strategic Petroleum Reserve (SPR) stores crude oil in 62 caverns located at four sites located along the Gulf Coast. The reserve contains approximately 700 million barrels (MMB) of crude oil. Most of the caverns were solution mined by the U.S. Department of Energy (DOE) and are typified as cylindrical in shape. In reality, the geometry, spacing, and depths of the caverns are irregular. Sandia, on behalf of DOE, is evaluating the mechanical integrity of the salt surrounding existing petroleum storage caverns in the Bayou Choctaw (BC) Salt Dome in Louisiana (Figure 1).

Geotechnical concerns arise due to the close proximity of the some of the caverns to each other (e.g., Caverns 15 and 17) or to the edge of salt (e.g., Cavern 20). In addition to the SPR caverns at BC, eight other caverns exist, which store various hydrocarbons and are operated by private industry. In addition, there are nine abandoned caverns, one of which collapsed (Cavern 7) and another (Cavern 4) which is believed to be in a quasi-stable condition. The integrity of wellbores at the interbed between the caprock and salt is another concern because oil leaks occurred at the interbed in the Big Hill site. When oil is withdrawn from a cavern in salt using freshwater, the cavern enlarges. As a result, the pillar separating caverns in the SPR fields is reduced over time due to usage of the reserve. The enlarged cavern diameters and smaller pillars reduce underground stability. It is necessary to establish a limit for the remaining pillar thickness between caverns without threatening the structural integrity of the caverns.

The three-dimensional finite element (FE) mesh capturing realistic geometries of BC site has been constructed using the sonar and seismic survey data obtained from the field. The mesh has to be consisting of hexahedral elements because the salt constitutive model, which will be used in the numerical simulation using this mesh, is coded for using hexahedral elements. Cubit, an automated mesh generation program developed by Sandia, was used to mesh the site. CUBIT is a full-featured software toolkit for robust generation of two- and three-dimensional finite element meshes (grids) and geometry preparation [Sandia, 2015]. The mesh contains the interbed between the caprock and salt top and the interface between the salt dome and surrounding in situ rock stratigraphy. Modeling of the leaching process of the caverns is performed by deleting elements along the walls of the cavern so that the cavern volume is increased by 15 percent per a drawdown. An additional layer of elements is considered on the outside of every cavern to check the analysis results at the cavern wall, roof, and floor.

This report provides various ideas and techniques to construct FE mesh capturing artificially and naturally formed geometries. Techniques to reduce the number of elements as much as possible to save on computer run time while maintaining the computational accuracy are introduced. The detailed steps and program command scripts are provided so people who are familiar with Cubit can duplicate the method and apply to other modeling. These techniques are also applicable to commercial mesh generation programs that have similar functionalities of Cubit.

1.1. Used Software

Create geometries and mesh generation:

Cubit 15.0b 64 bit Build 393458
Revised 2014-07-30
Copyright 2001 Sandia Corporation

Combine meshed blocks:

GJoin2 Version 1.32 (A GENESIS database combination program)
Revised 2009/12/02
Copyright 1988 Sandia Corporation

1.2. Points of Contact

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2. SITE DESCRIPTIONS

The BC salt dome, located in south-central Louisiana near Baton Rouge (Figure 1), was discovered in 1926. Since then over three hundred oil and gas wells have been drilled on and around the dome, as well as numerous shallow holes drilled into the caprock. Since 1937, Allied Chemical Corporation has drilled over twenty brine wells on the dome. In 1976, the Department of Energy (DOE) purchased eleven of these leached caverns and was storing approximately twenty two million barrels of crude oil in three of the caverns (numbered 15, 18, and 19), forming part of the SPR Program [Hogan, 1980].

Since 1980, SPR caverns 18, 19, and 20 have been enlarged substantially; Union Texas Petroleum (UTP) Caverns 6 and 26 have been constructed, and Caverns 101 and 102 have been leached by DOE. Cavern 102 was traded to UTP in a swap for Cavern 17, now used for SPR oil storage. In 1992 UTP converted its brine Cavern 24 to natural gas storage. UTP had leached in 1993 along the northeast dome edge [Neal et al., 1993].

Data from the 300 oil and gas wells were used to construct contour maps and cross sections of the salt dome and the overlying caprock. Figure 2 shows a plan view of the BC site with salt contour lines defining the approximate location of the salt dome edge. The locations of the six SPR caverns, nine UTP caverns, one inactive cavern, and seven abandoned caverns are included. A vertical cross section through Cavern 7 and Cavern 19 provides a geologic representation near the middle of the dome as shown Figure 3.

The surface and near surface sediments overlying the BC dome are of Pleistocene through Holocene age. The oldest sediments consist of proglacial sands and gravels with some clay layers. These sediments are overlain by alternating sequences of sand, silts and clays [Hogan, 1980].

Two distinct zones are found in the caprock at BC: an upper zone, termed the clay and gypsum zone (CGZ); and the lower zone, called the massive gypsum-anhydrite zone (GAZ). The CGZ is composed of layers of gypsum intercalated with clay. The proportion of clay to gypsum is highly variable, with generally more clay than gypsum. The GAZ is predominantly gypsum-anhydrite with minor amounts of clay, sand and gypsum [Hogan, 1980].

The top of the BC salt dome lies between 600 and 700 ft below the surface. The east flank dips gently downward to 1,500 feet where the dip increases to approximately 80º between 2,000 and 6,000 ft. The west flank of the dome is overhung between 1,000 and 5,000 ft. Below 6,000 to 8,000 ft, the slope of the salt surface diminishes to about 60º [Hogan, 1980].

The lithology surrounding the salt dome contains up to 30,000 ft of silts, sands, shales, limestones and evaporites. These sediments were deposited in a variety of sedimentary environments including desert basin, evaporating flat, ocean basin, and delta [Hogan, 1980].

The stratigraphy near the BC salt dome is shown in Figure 4. The top layer of overburden, which consists of sand, silts, and clays, has a thickness of 500 ft. The caprock, consisting of gypsum, anhydrite, and sand, is 160 ft thick. The bottom of the deepest cavern (Cavern 27) is at an depth of 6,280 ft. For the vertical direction constraint at the bottom of the model, sufficient thickness between the lowest cavern bottom and the model bottom is necessary to not affect the structural reaction by the bottom boundary. Therefore, the depth of the salt dome is considered up to 6,400 ft below the surface. All SPR caverns are located below 2,000 ft.

The faults shown in Figure 2 and Figure 3 will be ignored in the FEM model because the faults did not extend to the deep salt beyond the top of abandoned caverns thus the faults cannot affect the structural behavior of the SPR caverns. And, by ignoring the shear zone, the model of overburden and the cap rock layers are able to be simplified.

Figure 1: Bayou Choctaw SPR site location map

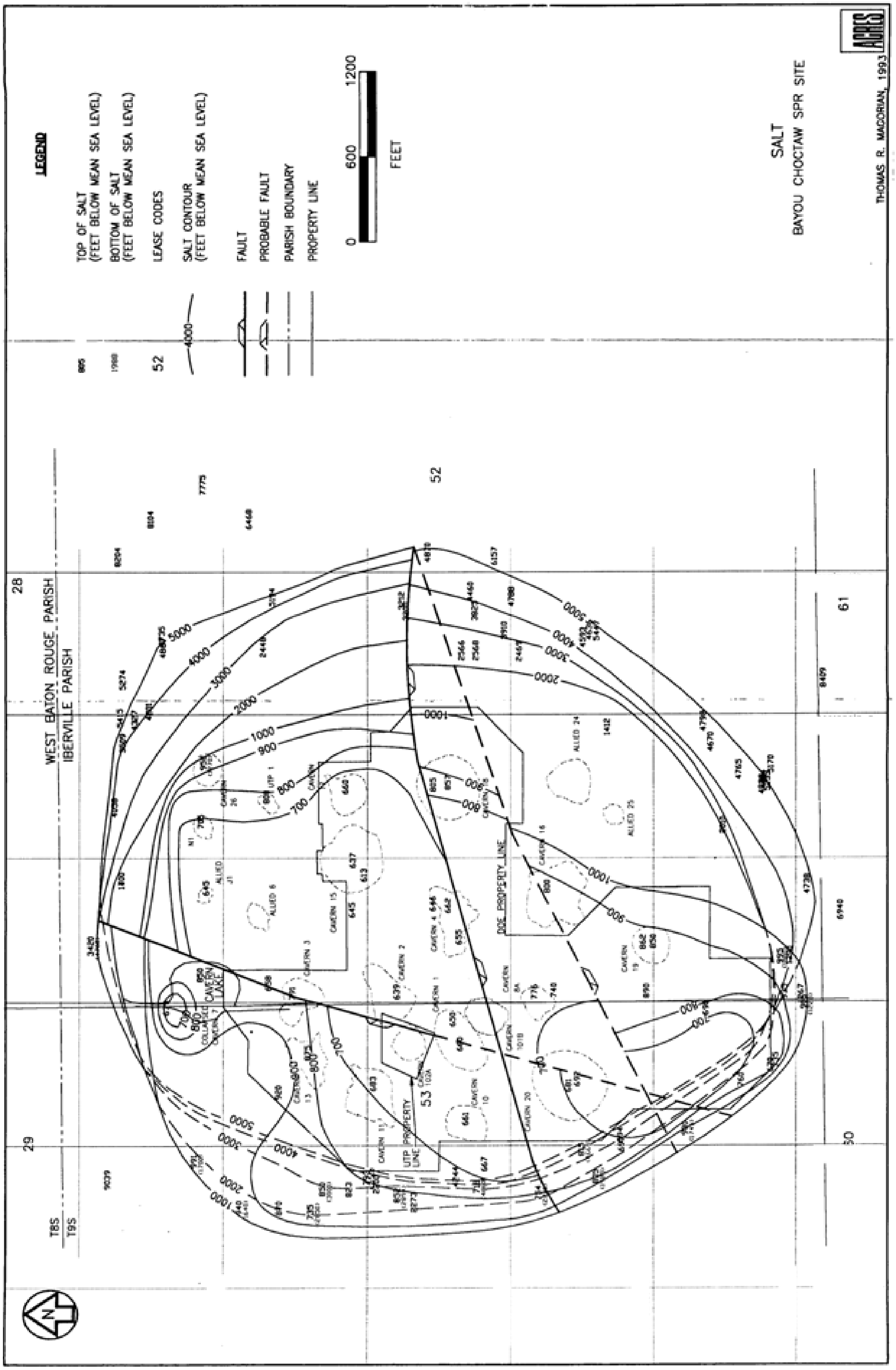

Figure 2: Bayou Choctaw site plan view [Neal et al., 1993]

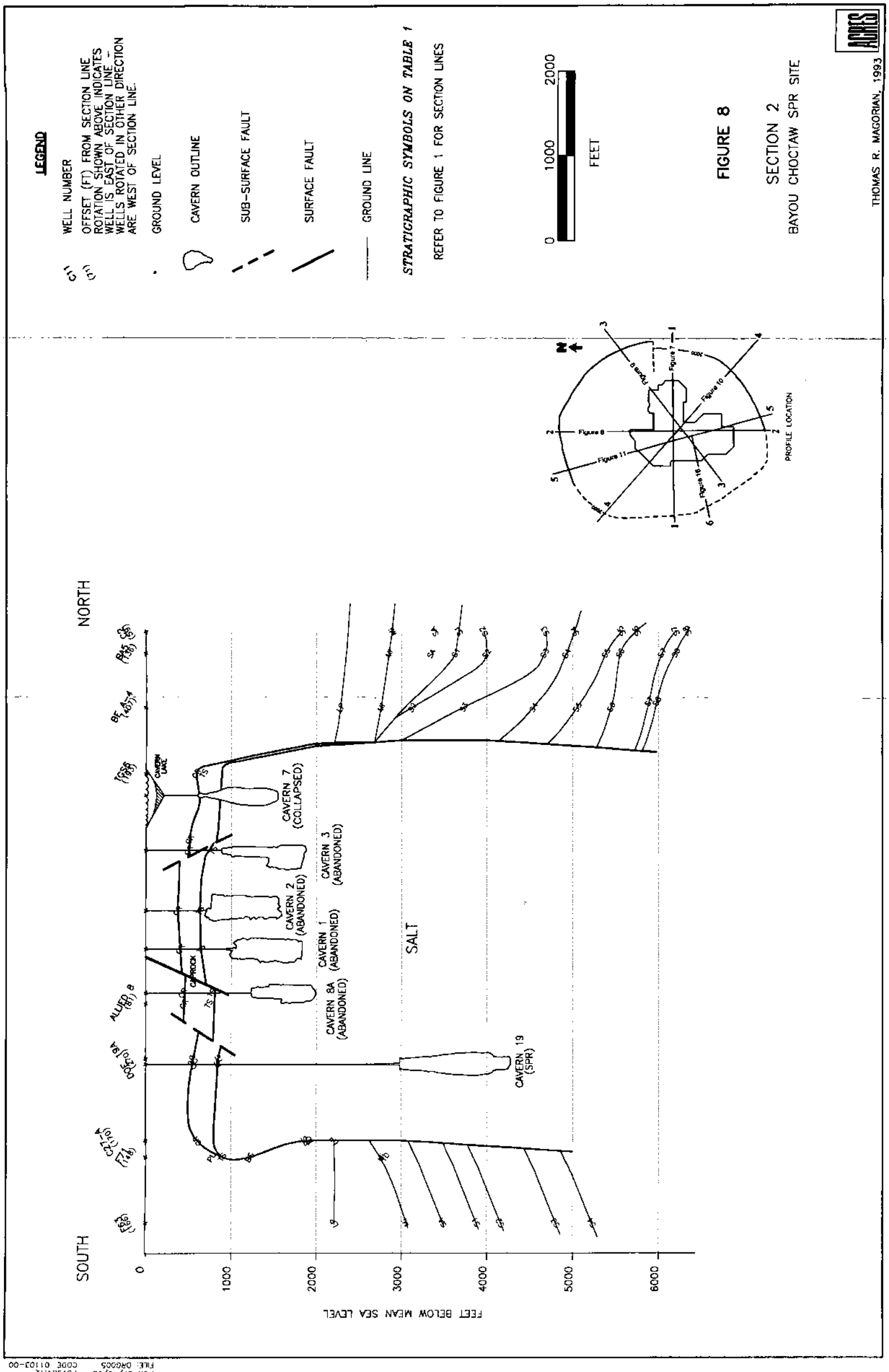

Figure 3: Cross-section through Cavern 7 and Cavern 19 [Neal et al., 1993]

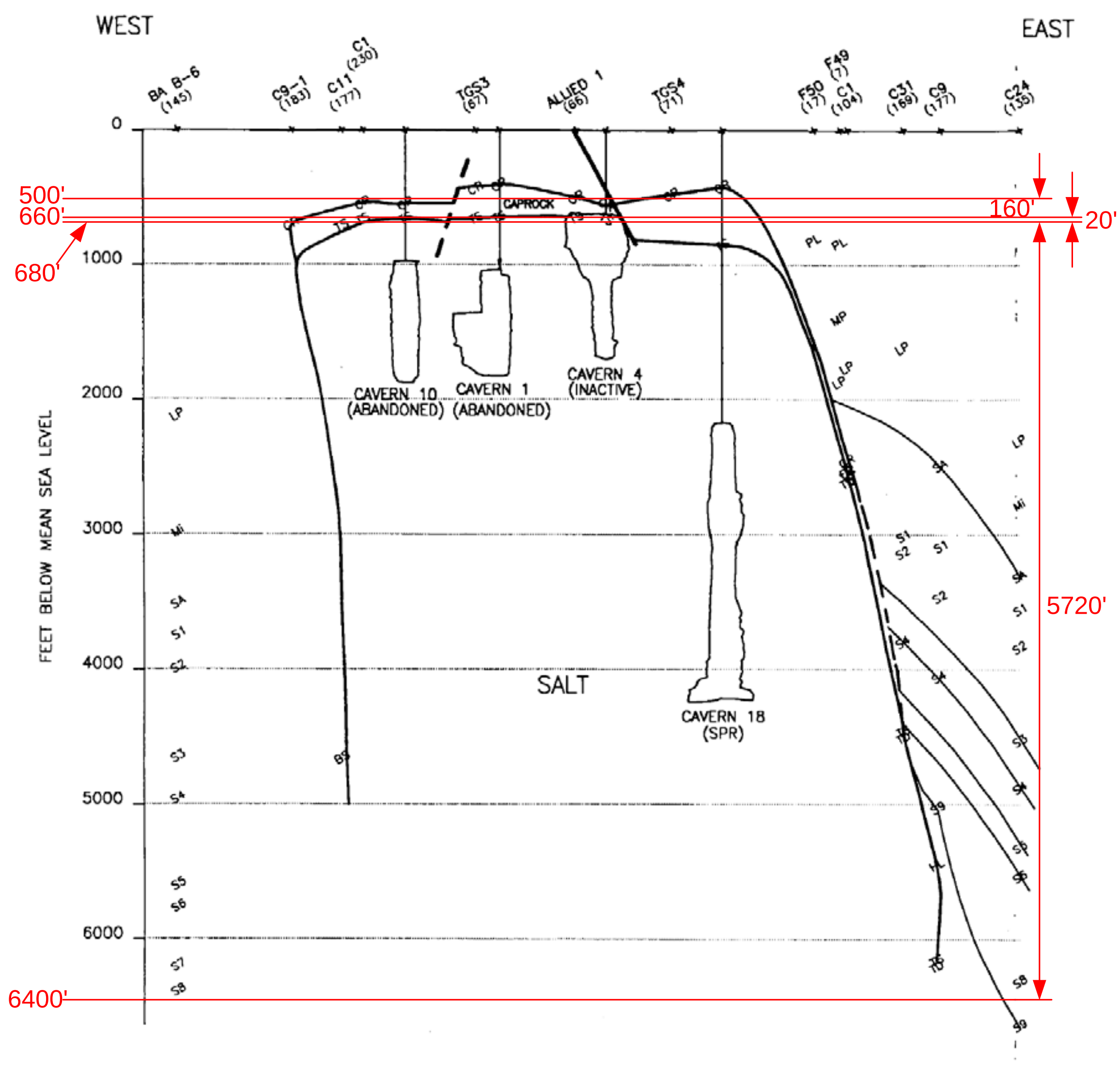

Figure 4: Stratigraphy near the Bayou Choctaw salt dome [Neal et al., 1993] and the thickness of each layer used for modeling.

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3. TERMINOLOGY AND DEFINITION

3.1. Cavern Groups

From a perspective of mesh generation, the caverns in the BC salt dome are classified into two groups, non-SPR and SPR caverns. The non-SPR caverns are classified further into two groups, normal and abnormal caverns. The SPR caverns are classified into three sub-groups with number of "onion skins" (the number of pre-meshed layers corresponding to the salt lost around the perimeter of the cavern during a drawdown leach), a one skin group, four skins group, and six skins group.

The following caverns are classified as Non-SPR Caverns:

- Normal group: BC-1, BC-2, BC-3, BC-6, BC-8, BC-10, BC-11, BC-13, BC-16, BC-24, BC-25, BC-26, BC-27, BC-28, BC-J1, BC-N1, and BC-UTP
- Abnormal group: BC-4, BC-7

The normal caverns exist only within the salt dome. The abnormal cavern BC-4 was leached into the salt dome and the top of the cavern extended into the caprock layer. BC-7 collapsed in 1954 and was filled with overburden material which formed a lake on the surface above the cavern top. Therefore, the cavern boundary extends into three lithologic layers such as the salt dome, caprock and overburden layers.

The non-SPR caverns, because they are non-operational caverns, do not require a drawdown leach. However, one onion skin with the same thickness of one drawdown leach as will be described in Section 4.1 will be constructed in the mesh for these caverns to check the analysis results at the cavern wall, roof, and floor. The cavern skin can be separated from the entire mesh. The amount of numerical result data in the skin block is much less than in the whole mesh. Examining the result in the skin volumes makes storage and analysis efforts more efficient. The small amount of the data can be handled easily to check various structural behaviors of the cavern.

The following caverns are classified as SPR caverns, based on the expected maximum number of viable drawdowns each cavern may be allowed:

- One skin group: BC-20
- Four skins group: BC-15 and BC-17
- Six skins group: BC-18, BC-19, BC-101, and BC-102

The one skin cavern, BC-20, is close to the dome edge (less than 100 feet away). This close proximity creates two problems. The first is a physical problem, in that the closeness to the salt dome boundary poses potential cavern collapse issues (this issue is one of the driving factors for developing the meshing technique). The second is a meshing problem; the addition of even one onion skin in the narrow pillar between the cavern wall and the dome edge will probably induce generation of poor mesh element shapes. Thus, BC-20 is considered a zero drawdown-leach cavern like the non-SPR caverns. The single onion skin will be used to check the analysis results.

For the caverns in the four skins group, BC-15 and BC-17, are close to each other. More than four onion skins would induce poor mesh element shapes. Thus, three drawdown leaches are considered. Three skins will be used for drawdown leaches and checking the analysis results. The fourth outmost skin will be used only for checking the results.

The caverns in the six skins group are considered capable of undergoing five drawdown leaches. Five skins will be used for drawdown leaches and checking the analysis results. The sixth outmost skin will be used only for checking the results.

3.2. Terminology

Terms used in this report are defined as Table 1.

Table 1: Description of each term

Term	Descriptions
Stratigraphy	The stratigraphy near Bayou Choctaw site consists of four layers such as overburden, caprock, salt dome, and surrounding rock
Layer (horizontal)	Horizontal layer consists of blocks for overburden, caprock, interbed
Column (vertical)	Vertical column consists of blocks for caverns, interface, dome, surrounding rock, etc.
Block	Block consists of element blocks/volumes
Volume	Volume consists of surfaces
Surface	Surface consists of curves
Curve	Line between two vertices
Vertex	Point of geometry (Sonar/seismic data point or manually calculated point)
Meshed volume	Meshed volume consists of hexahedral elements
Element block	Each meshed volume is numbered as element block. Block is a geometrical term, while element block is a FE term.
Element	Element consists of facets
Facet	Facet consists of bars/element edges
Element bar/edge	Element bar/edge consists of nodes
Interval	Element bar/edge between nodes. A curve between vertices is divided by intervals.
Node	Point of mesh
Translation	For a translation transformation, the two-dimensional mesh is displaced a specified amount in the Z-direction. The three-dimensional mesh is then generated in the volume between the original mesh and the displaced mesh. The two-dimensional mesh lies in the X-Y coordinate (horizontal) plane in this report.
Element level	When the 2D mesh is translated to create the 3D mesh, element layers are created. Each element layer is called element level.
Slice volume	Cavern/Dome/Far-field volume is cut horizontally by 20 ft thick vertical layers.
Slice block	Slice block consists of slice volumes

3.3. File Naming Convention

The file names created during the process are listed as Table 2. The symbol # indicates a digit; * indicates a wild card; and the suffix .jou is a journal files suffix for input files to the Cubit meshing program [Sandia, 2015].

Table 2: File naming convention

File name	Descriptions
Play journal files	
bc_####.jou	To create the dome slice block whose bottom elevation is -#### ft
bot_0500_surface.jou	To create/mesh/save the block in the overburden layer
bot_0500_surface_wall.jou	To create/mesh/save the block in the overburden layer (for BC-7 only)

File name	Descriptions
bot_0500_up_ob.jou	To create/mesh/save the surrounding rock block in the overburden layer. The related sub files is “mesh_wall_up_ob.jou”
bot_0640_up_cr.jou	To create/mesh/save the surrounding rock block in the caprock layer. The related sub files is “mesh_wall_up_cr.jou”
bot_####_above.jou	To create/mesh/save the block above a cavern. The meshed block has neither side sets nor node sets. Sub files are “mesh_above_wo_ss.jou” and “save_wo_ns_ss.jou”
bot_####.jou	To create/mesh/save the cavern, dome, and surrounding rock blocks whose bottom elevation is -#### ft. The mesh is created downward from the top surface of the block. The reference mesh comes from the block right above.
bot_####_up.jou	To create/mesh/save the dome and surrounding rock blocks whose bottom elevation is -#### ft. The mesh is created upward from the bottom surface of the block. The reference mesh comes from the block right below.
bot_####_above_up.jou	To create/mesh/save the dome blocks in the overburden and caprock layers. The mesh is translated upward from the bottom surface of the block. The reference mesh is the top of the block right below.
bot_####_roof.jou	To create/mesh/save the cavern roof block whose bottom elevation is -#### ft. The reference mesh comes from the block right above.
bot_####_up_smth1st.jou	To create/mesh/save the dome and surrounding rock slice blocks whose bottom elevation is -#### ft. The mesh is created upward from the bottom surface of the block. The reference mesh comes from the block right below. The mesh smoothing process conducts first.
bot_####_ smth1st.jou	To create/mesh/save the dome and surrounding rock slice blocks whose bottom elevation is -#### ft. The mesh is created downward from the top surface of the block. The reference mesh comes from the block right above. The mesh smoothing process conducts first.
bot_####_mean_ratio.jou	To create/mesh/save the dome and surrounding rock slice blocks whose bottom elevation is -#### ft. The mesh is created downward from the top surface of the block. The reference mesh comes from the block right above. The mesh smoothing process conducts using scheme mean ratio.
bot_####_base.jou	To create/mesh/save the dome and surrounding rock blocks whose bottom elevation is -#### ft. The mesh is created as a reference block. Other dome blocks are created upward/downward from this block. Other surrounding rock blocks are created upward from this block.
bot_####_below.jou	To create/mesh/save the column block below a cavern/dome
bot_6400_bottom.jou	To create/mesh/save the column block between a cavern/dome bottom and model bottom
bot_####_w_ss.jou	To create/mesh/save the cavern block with side sets (for BC-4 and BC-7)
bot_####_floor.jou	To create/mesh/save the cavern block which top is defined as a floor of cavern
Vertex files	
vtx_####.jou	To create vertices which consist of X-, Y-, Z- coordinates converted from sonar data. The elevation of the bottom vertices is -#### ft.
Play Cubit sub-journal files	
create_vol.jou	Cubit sub-journal file to create the volumes
setup.jou	Cubit sub-journal file to set up the graphic windows size which default is 1040(h(x800(v) pixels
define_group_#skin.jou	Cubit sub-journal file to group specific vertices/curves/surfaces. Use for # skin onion blocks
mesh_surface	Cubit sub-journal file to create mesh in the cavern slice blocks in the overburden layer. This is the reference mesh block of a cavern. The mesh translates downward

File name	Descriptions
	from this block.
mesh_above_wo_ss.jou	Cubit sub-journal file to create mesh in the slice blocks above a cavern without side set
mesh_below_wo_ss.jou	Cubit sub-journal file to create mesh in the slice blocks below a cavern without side set
mesh_roof.jou	Cubit sub-journal file to create mesh in the roof block of a cavern with side set
mesh_wall.jou	Cubit sub-journal file to create mesh in the cavern inside and wall blocks of a cavern with side set
mesh_floor.jou	Cubit sub-journal file to create mesh in the floor block of a cavern with side set
save.jou	Cubit sub-journal file to save Cubit, Genesis, abstract, and log files
save_wo_ns_ss.jou	Cubit sub-journal file to save Cubit, Genesis, abstract, and log files without node set and side set
save_wo_ss.jou	Cubit sub-journal file to save Cubit, Genesis, abstract, and log files without side set
import_####.jou	Cubit sub-journal file to import the cavern blocks with which punch the dome slice block
*.gjn	GJOIN script file to combine meshed blocks
Output files	
bc*_####.cub	Cubit file of the block whose bottom elevation is -#### ft
bc*_####_skn.cub	Cubit file of the outmost skin block whose bottom elevation is -#### ft
bc*_####.g0	Genesis file of the block whose bottom elevation is -#### ft
bc*_####.abs	Abstract file which contains mesh quality data and executive exodus summary
bc*_####.err	Error file which contains error messages when Cubit error occurs
bc*_####.log	Log file which contains every logging message during Cubit execution

3.4. Parameters and Group

Table 3 lists the parameters used in Cubit input journal file for APREPRO[1] process. To journalize a Cubit input file, the group names of specific vertices, curves and surfaces are defined as listed in Table 4.

Table 3: Parameters used in Cubit input journal for APREPRO process

Parameter	Relationship	Descriptions
TELE	-	Top elevation (ft)
BELE	-	Bottom elevation (ft)
CID	= Cavern No.[2]×10000	Cavern identification
TID	= CID-TELE	ID to define block, volume, side set, node set, etc.
BID	= CID-BELE	ID to define block, volume, side set, node set, etc.
NVTX	-	Number of vertices on a perimeter
NDL	-	Number of drawdown leaches or onion skins
NVOL	= NDL+1	Number of volumes
TNVTX	= NVTX×NVOL×2	Total number of vertices in a slice of volume

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1 An Algebraic Preprocessor for Parameterizing Finite Element Analyses developed by Sandia National Laboratories.

2 Cavern number of BC-1 is 001 as defined in Table 5, then CID=10000. Cavern number of BC-101 is 101, then CID=1010000. Cavern number of BC-J1 is 031, then CID=310000. Dome number is 999, then CID=9990000.

Parameter	Relationship	Descriptions
TNSB	= NVOL×2	Total number of sheet bodies in a slice of volume
VI0	= 0	ID to define a slice of inner volume
VI1	= 1	ID to define a slice of the 1st onion skin volume
VI2	= 2	ID to define a slice of the 2nd onion skin volume
VI3	= 3	ID to define a slice of the 3rd onion skin volume
VI4	= 4	ID to define a slice of the 4th onion skin volume
VI5	= 5	ID to define a slice of the 5th onion skin volume
VI6	= 6	ID to define a slice of the 6th onion skin volume
TSI0	= 1	Top surface ID of the inner volume slice
TSI1	= 2	Top surface ID of the 1st onion skin volume slice
TSI2	= 3	Top surface ID of the 2nd onion skin volume slice
TSI3	= 4	Top surface ID of the 3rd onion skin volume slice
TSI4	= 5	Top surface ID of the 4th onion skin volume slice
TSI5	= 6	Top surface ID of the 5th onion skin volume slice
TSI6	= 7	Top surface ID of the 6th onion skin volume slice
BSI0	= TSI0+NVOL	Bottom surface ID of the inner volume slice
BSI1	= TSI1+NVOL	Bottom surface ID of the 1st onion skin volume slice
BSI2	= TSI2+NVOL	Bottom surface ID of the 2nd onion skin volume slice
BSI3	= TSI3+NVOL	Bottom surface ID of the 3rd onion skin volume slice
BSI4	= TSI4+NVOL	Bottom surface ID of the 4th onion skin volume slice
BSI5	= TSI5+NVOL	Bottom surface ID of the 5th onion skin volume slice
BSI6	= TSI6+NVOL	Bottom surface ID of the 6th onion skin volume slice
VDL0	= TNSB+1	The inner volume slice ID
VDL1	= TNSB+2	The 1st onion skin volume slice ID
VDL2	= TNSB+3	The 2nd onion skin volume slice ID
VDL3	= TNSB+4	The 3rd onion skin volume slice ID
VDL4	= TNSB+5	The 4th onion skin volume slice ID
VDL5	= TNSB+6	The 5th onion skin volume slice ID
VDL6	= TNSB+7	The 6th onion skin volume slice ID
skn	= VDL1 or VDL4 or VDL6	Volume ID to save the cavern onion skin volume separately
V001	= 2×VDL1	The 1st onion skin volume ID of BC-1
V002	= V001+VDL1	The 1st onion skin volume ID of BC-2
V003	= V002+VDL1	The 1st onion skin volume ID of BC-3
V004	= V003+VDL1	The 1st onion skin volume ID of BC-4
V006	= V004+VDL1	The 1st onion skin volume ID of BC-6
V007	= V006+VDL1	The 1st onion skin volume ID of BC-7
V008	= V007+VDL1	The 1st onion skin volume ID of BC-8
V010	= V008+VDL1	The 1st onion skin volume ID of BC-10
V011	= V010+VDL1	The 1st onion skin volume ID of BC-11
V013	= V011+VDL1	The 1st onion skin volume ID of BC-13
V015	= V013+VDL1×2+3	The 4th onion skin volume ID of BC-15
V016	= V015+VDL1	The 1st onion skin volume ID of BC-16
V017	= V016+VDL1×2+3	The 4th onion skin volume ID of BC-17
V018	= V017+VDL1×3+3	The 6th onion skin volume ID of BC-18
V019	= V018+VDL1×3+3	The 6th onion skin volume ID of BC-19
V020	= V019+VDL1	The 1st onion skin volume ID of BC-20
V024	= V020+VDL1	The 1st onion skin volume ID of BC-24

Parameter	Relationship	Descriptions
V025	= V024+VDL1	The 1st onion skin volume ID of BC-25
V026	= V025+VDL1	The 1st onion skin volume ID of BC-26
V027	= V026+VDL1	The 1st onion skin volume ID of BC-27
V028	= V027+VDL1	The 1st onion skin volume ID of BC-28
V031	= V028+VDL1	The 1st onion skin volume ID of BC-J1
V032	= V031+VDL1	The 1st onion skin volume ID of BC-N1
V033	= V032+VDL1	The 1st onion skin volume ID of BC-UTP
V101	= V019+VDL1×3+3	The 6th onion skin volume ID of BC-101
V102	= V101+VDL1×3+3	The 6th onion skin volume ID of BC-102
VLST	= V102	The last onion skin volume
VLSC	= VLST+NCS×2	The last created volume ID

Table 4: Group names used in Cubit input journal

Group	Descriptions
tcurv	curves on the top of the volume
bcurv	curves on the bottom of the volume
tsurf	surfaces on the top of the volume
bsurf	surfaces on the bottom of the volume
msurf	surfaces on the wall of the volume
cdl0w	curves on the wall of the inner volume (zero drawdown volume)
sdl0t	surfaces on the top of the inner volume (zero drawdown volume)
sdl0w	surfaces on the wall of the inner volume (zero drawdown volume)
sdl0b	surfaces on the bottom of the inner volume (zero drawdown volume)
cdl#w	curves on the wall of the #th onion skin volume
sdl#t	surfaces on the top of the #th onion skin volume
sdl#w	surfaces on the wall of the #th onion skin volume
sdl#b	surfaces on the bottom of the #th onion skin volume
vdl0t	vertices on the top of the inner volume (zero drawdown volume)
cew	curves on the east and west sides of surrounding rock
cns	curves on the north and south sides of surrounding rock
sbot	surfaces on the bottom of the volume of surrounding rock
sew	surfaces on the east and west sides of surrounding rock
sns	surfaces on the north and south sides of surrounding rock

3.5. Block, Side Set, and Node Set

3.5.1. Cavern and dome slices

The format of slice block ID:

`Block ccc###d`

ccc = cavern and dome ID (1~102 for cavern, 999 for dome)

###0 = -elevation (ft) at the bottom of slice block (last digits of elevations are always 0)

d = onion skin (assign d instead of 0)

0 = inner cavern slice

1 = the 1st onion skin slice

2 = the 2nd onion skin slice

3 = the 3rd onion skin slice

4 = the 4th onion skin slice

5 = the 5th onion skin slice

6 = the 6th onion skin slice

The format of slice side set ID:

`Sideset ccc###d`

ccc###d = the same format of the slice block ID

The format of slice node set ID:

`Nodeset ccc###d`

ccc = cavern and dome ID (1~102 for cavern, 999 for dome)

###d = 0003 (because node sets at the bottom only of the cavern columns are needed, so 0003 is used to express the model bottom `Nodeset 3` as defined in the following section)

3.5.2. Cavern and dome column

The format of cavern column node set ID:

`Nodeset 3ccc`

ccc = cavern and dome ID (001~102 for cavern, 999 for dome)

Because node sets at the bottom of the cavern columns are needed only, so 3 is used to express the model bottom `Nodeset 3` as defined in the following section.

3.5.3. Entire model

The format of block ID:

`Block mcccdx`

m = material layers (1~5)

1 = salt

2 = overburden

3 = caprock

5 = surrounding rock (far field)

8 = interbed between caprock and salt

9 = interface between dome and surrounding rock

ccc = cavern ID (001~102)

d = onion skin (0~6)

None = block in non-cavern layer

0 = inner cavern block

1 = the 1st onion skin block

2 = the 2nd onion skin block

3 = the 3rd onion skin block

4 = the 4th onion skin block

5 = the 5th onion skin block

6 = the 6th onion skin block

x = wall, roof, and floor

None = wall

7 = roof (top)

9 = floor (bottom)

The format of side set ID:

Sideset cccdx

ccc = cavern ID (1~102)

d = skin (0~5)

x = wall, roof, and floor

9 = floor (bottom) for BC-7 only

The format of node set ID:

Nodeset n

n = node set ID

1 = X-component, Model Left (West side) and Model Right (East side)

2 = Y-component, Model Front (South side) and Model Back (North side)

3 = Z-component, Model Bottom

4. MODEL DESCRIPTION

4.1. Basic Rule

Finite element codes such as Sierra/Adagio are designed to conduct simulations with finite elements that are either tetrahedral or hexahedral. Two constitutive models, i.e. power law creep (PLC) model and multi-mechanism deformation (M-D) model, are coded as material models to represent the salt behavior in Adagio. These two material models are programmed in Sierra/Adagio assuming eight-node hexahedral elements. Therefore, the mesh for the BC SPR site has to be constructed with hexahedral elements. Hexahedral elements include 6 convex quadrilateral sides, or facets, with the nodes for these facets being the eight nodes for the element. The cavern boundaries such as the ceiling, wall, and floor are obtained from sonar measurements, and the irregular geometries of these boundaries ultimately require various shapes of facets. Similarly, the geometry of the flank of the salt dome, obtained from seismic measurements, also consists of complicated shapes of facets. To construct a mesh with convex hexahedral elements for a geological volume keeping the complicated geometry as much as possible, the following rules were established and followed:

1. Each perimeter (cavern and dome) consists of the same number of vertices
2. Reference distance between vertices on a perimeter is:
    a. about 20 ft for caverns
    b. about 80 ft for dome
3. The vertical thickness of an element level is kept constant at 20 ft
4. 15% cavern volume increase for each drawdown leach

Figure 5 shows the meshed volume of BC-20 with the sonar image as an example. The circumference at each elevation varies. The average circumference is calculated from averaging the diameter obtained from the sonar data at each elevation. The number of intervals on a circumference is calculated to be 90 by dividing the average circumference by 20 ft, and then kept constant for each vertical layer. Thus the interval size between two vertices varies with elevation. The cavern volume consists of 90 lines from the ceiling to the floor as a blue line in Figure 5. The thickness of each element level is kept constant at 20 ft. Using this rule, coordinates of each vertex are resampled from the sonar image (will be described in Chapter 5).

Modeling of the leaching process of the caverns is performed by deleting a pre-meshed block of elements along the walls of the cavern so that the cavern volume is increased by 15 percent per drawdown. The 15% volume increase is typical for a standard freshwater drawdown, although salt quality can vary that amount. Also, typical leaching processes tend to increase cavern radius more at the bottom of the cavern than at the top, with very little change to the roof and floor of the cavern. For the purposes of this modeling effort for Bayou Choctaw, leaching is assumed to add 15% to the volume of the cavern, and is assumed to occur uniformly along the entire height of the cavern, with no leaching in the floor or roof of the caverns. Each leaching layer, or onion skin, is built around the perimeter of the meshed cavern volume using the same rules stated previously.

The X-axis of model is in the E-W (East-West) direction, Y-axis is in the N-S (North-South) direction, and Z-axis is the vertical direction. To realize the leaching process in the mesh, the coordinates of a vertex (X_1, Y_1) in Figure 6 have to be calculated for the first drawdown:

The coordinates of the center at each element level are:

$$X_c = \frac{\sum_{i=1}^{N} X_i}{N}, Y_c = \frac{\sum_{i=1}^{N} Y_i}{N} \tag{1}$$

where, N = number of vertices = 90 for BC-20, X_i, Y_i are shown in Figure 5.

The distance between the center point and a vertex (X_0, Y_0) on the perimeter of original cavern volume:

$$L_0 = \sqrt{(X_C - X_0)^2 + (Y_C - Y_0)^2} \tag{2}$$

The distance between the center point and a vertex (X_1, Y_1) on the perimeter of one drawdown leached volume:

$$L_1 = L_0\sqrt{1 + R_v} \tag{3}$$

where, $R_v =$ volume increase rate = 15% for BC salt

Then, the coordinate of a vertex (X_1, Y_1) on the perimeter of one drawdown leached volume are calculated as:

$$X_1 = X_C + (X_0 - X_C) \cdot \frac{L_1}{L_0},\ Y_1 = Y_C + (Y_0 - Y_C) \cdot \frac{L_1}{L_0} \tag{4}$$

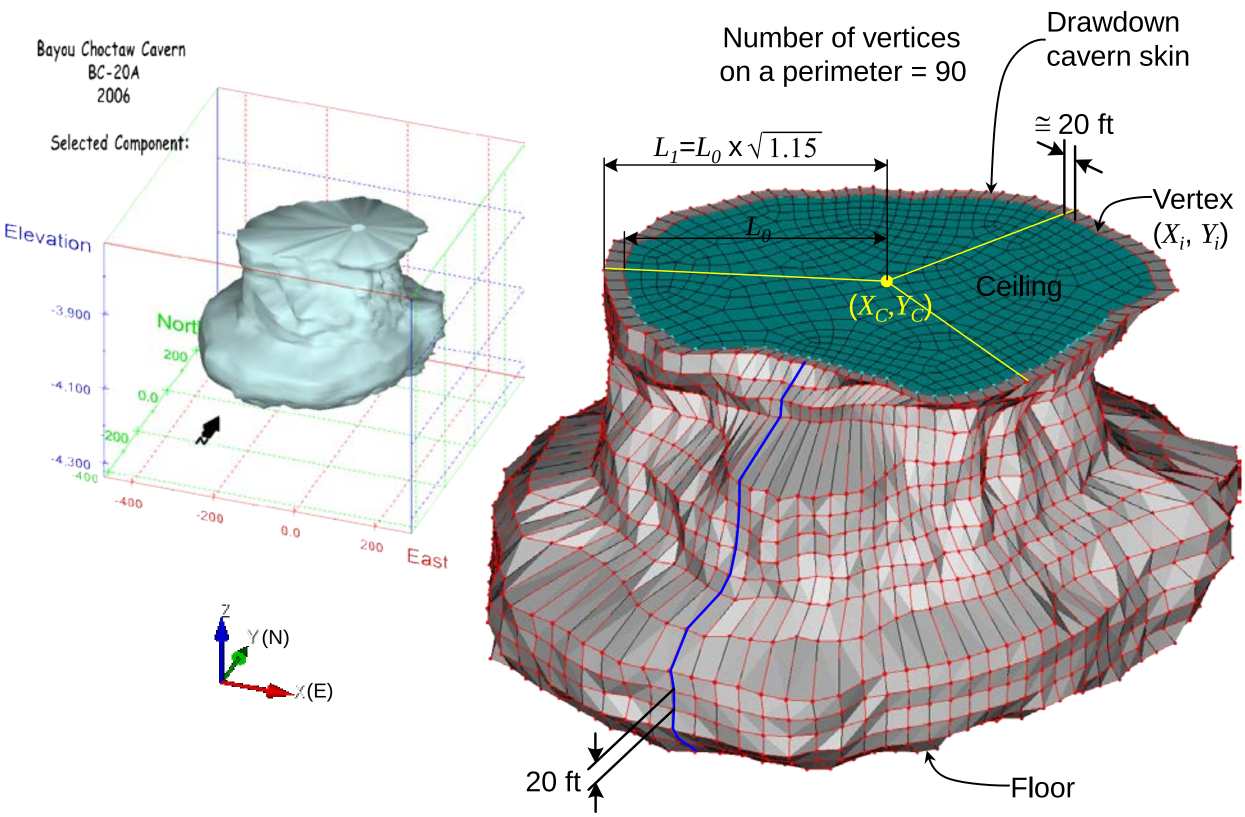

Figure 5: Sonar image (left) and meshed volume of Bayou Choctaw Cavern 20 with one drawdown cavern skin

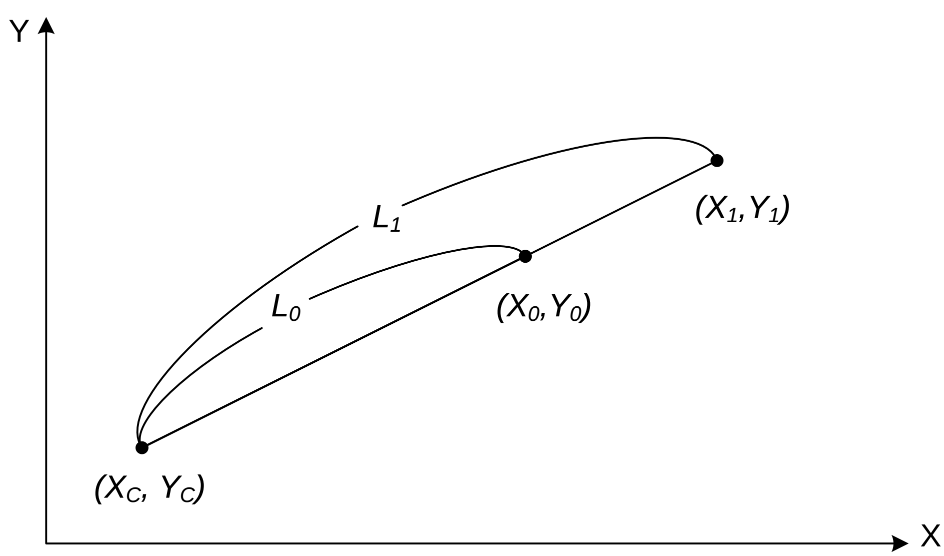

Figure 6: Calculation of coordinates of a vertex for the 1st drawdown cavern skin

4.2. Work Flow

4.2.1. Overall

Figure 7 shows the overall work flow to construct a mesh capturing realistic geometries of the Bayou Choctaw site. The BC 3D seismic data was shot in 1994 for petroleum exploration. The sonar surveys on BC caverns were performed on the dates as listed in Table 5. The cavern numbers are also defined to be used in the Cubit input journal in Table 5. The top and bottom elevations of each cavern are calculated in the resampling step will be mentioned in Chapter 5. The data from the surveys are manipulated in the MVS[3] geologic modeling software suite. This step is necessary to provide a full three-dimensional surface model of the sonar and seismic data.

The vertices output for the geomechanical simulations need to be at specific depth intervals which may not correspond to the actual sonar sampling locations. Continuous three-dimensional surface models of the survey data are created. The continuous three-dimensional surface allows sampling at any needed depth. This resampling step is performed through an algorithm coded using Python. Then, the resampled node coordinates data sets for the dome and caverns are generated as the output in this step.

The resampled nodal data are converted into Cubit vertices data through MS Excel manipulation. 3D hexahedral element meshes for 26 caverns, salt dome, caprock, overburden, interbed, and interface between the dome and surrounding rock of BC SPR site, are constructed using various functions in Cubit. Mesh quality is checked for each block in Cubit. All meshes are combined into one Genesis hexahedral FE mesh using GJOIN. The solver, Adagio, will be executed with the mesh to calculate the geomechanical behavior of caverns, dome and surrounding lithologies.

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3 MVS (Mining Visualization System) is C Tech’s flagship product for state-of-the art analysis and visualization. MVS was designed from the ground up to meet the demanding requirements of underground and surface mining analysis; however, its tools are also used by civil engineers and advanced environmental modelers.

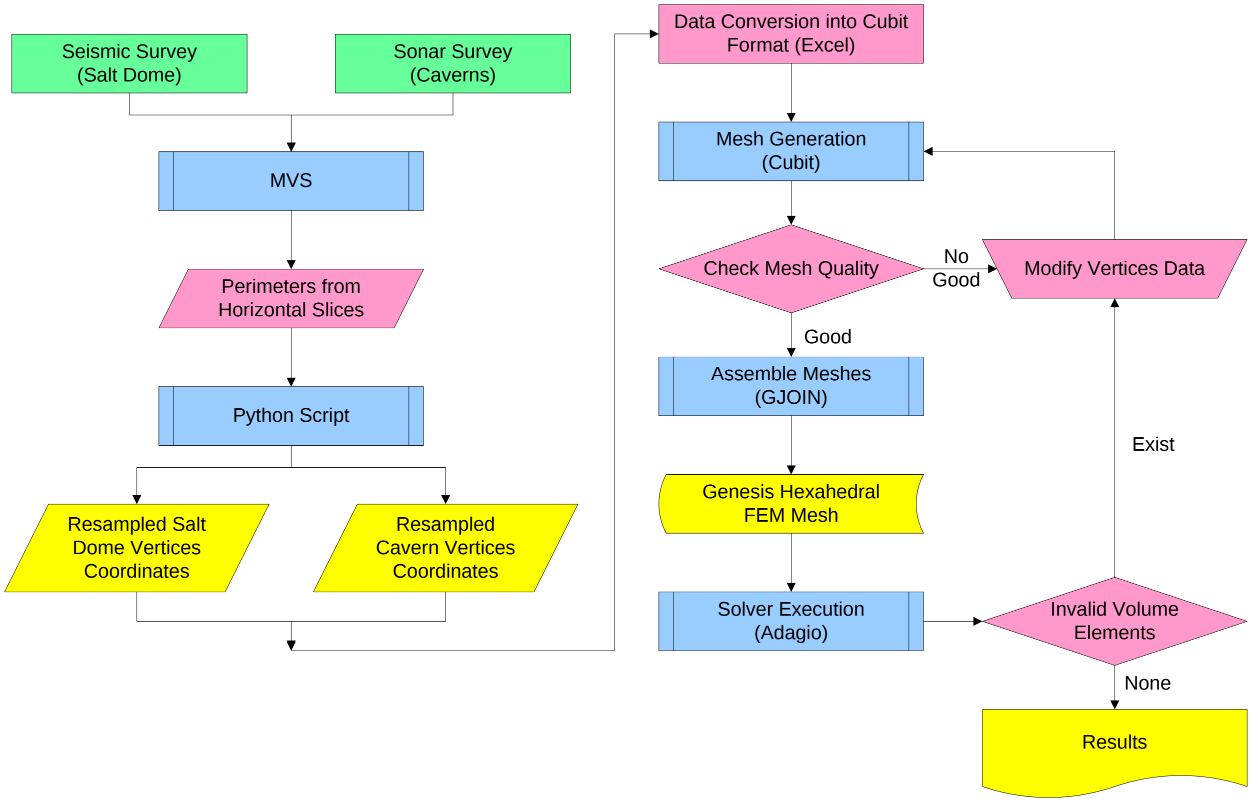


Figure 7: Work flow for the simulation using FE mesh capturing realistic geometries of Bayou Choctaw site.

Table 5: Date of the last sonar survey on BC caverns, cavern number, top and bottom elevations of the caverns

ID	Date of the sonar survey	Cavern/Dome number	Top elevation (ft)	Bottom elevation (ft)
BC-1	05-30-1980	001	-1040	-1820
BC-2	07-28-1983	002	-780	-1520
BC-3	07-13-1977	003	-1020	-1840
BC-4	07-30-2013	004	-640	-1660
BC-6	11-01-2006	006	-1240	-1560
BC-7	Collapsed in 1954	007	0	-1940
BC-8	05-31-1980	008	-1300	-1940
BC-10	09-13-1973	010	-1000	-1880
BC-11	03-10-1978	011	-1120	-1740
BC-13	08-13-1977	013	-1120	-1860
BC-15	04-15-2009	015	-2600	-3260
BC-16	06-28-2004	016	-2620	-3200
BC-17	04-16-2009	017	-2740	-3960
BC-18	01-06-2009	018	-2160	-4160
BC-19	04-14-2009	019	-2980	-4200

ID	Date of the sonar survey	Cavern/Dome number	Top elevation (ft)	Bottom elevation (ft)
BC-20	12-13-2013	020	-3820	-4180
BC-24	04-16-1997	024	-3100	-4320
BC-25	10-30-2007	025	-2580	-5640
BC-26	10-11-1996	026	-2300	-3320
BC-27	10-28-2007	027	-5940	-6280
BC-28	10-29-2007	028	-4700	-6240
BC-J1	07-27-2006	031	-2860	-3900
BC-N1	12-05-2003	032	-1920	-3480
BC-UTP	10-14-2006	033	-2380	-3480
BC-101	04-14-2009	101	-2580	-4780
BC-102	02-22-2012	102	-2640	-5220
Dome		999	0	-6400

4.2.2. Cavern

Figure 8 shows the procedure to create a cavern mesh of BC-20 as an example. The sonar image of the cavern boundary including cavern ceiling, wall, and floor is obtained from the sonar survey. The 3D-coordinates of the vertices are resampled from the sonar image. Cavern slice block 20 ft thick layers are generated using the coordinates of vertices. The cavern mesh has to be composed of hexahedral elements. The hexahedral element shape has to be translated from the top through the bottom of the model. Therefore, the upper and lower salt blocks, interbed block, caprock block, and overburden block are needed. The hexahedral element meshes are created in the overburden layer first. The quadrilateral element shapes on the top surface of the overburden block translate to the bottom surface of the block. The element shapes on the bottom surface of the overburden block transfer to the top surface of the caprock block through merging the surfaces. In the same manner, the hexahedral element shapes of the overburden block are translated through the interbed, upper salt, cavern ceiling, cavern body, cavern floor, and lower salt blocks. Those meshed blocks are assembled into the cavern column. The upper salt block leans to the left (west) because the dome leans to the west. To avoid poor shape elements in the salt between the dome edge and the upper salt block, the upper salt column needs to be parallel to the dome edge as much as possible. In the same manner, the other 25 cavern columns are generated for the remaining 25 caverns.

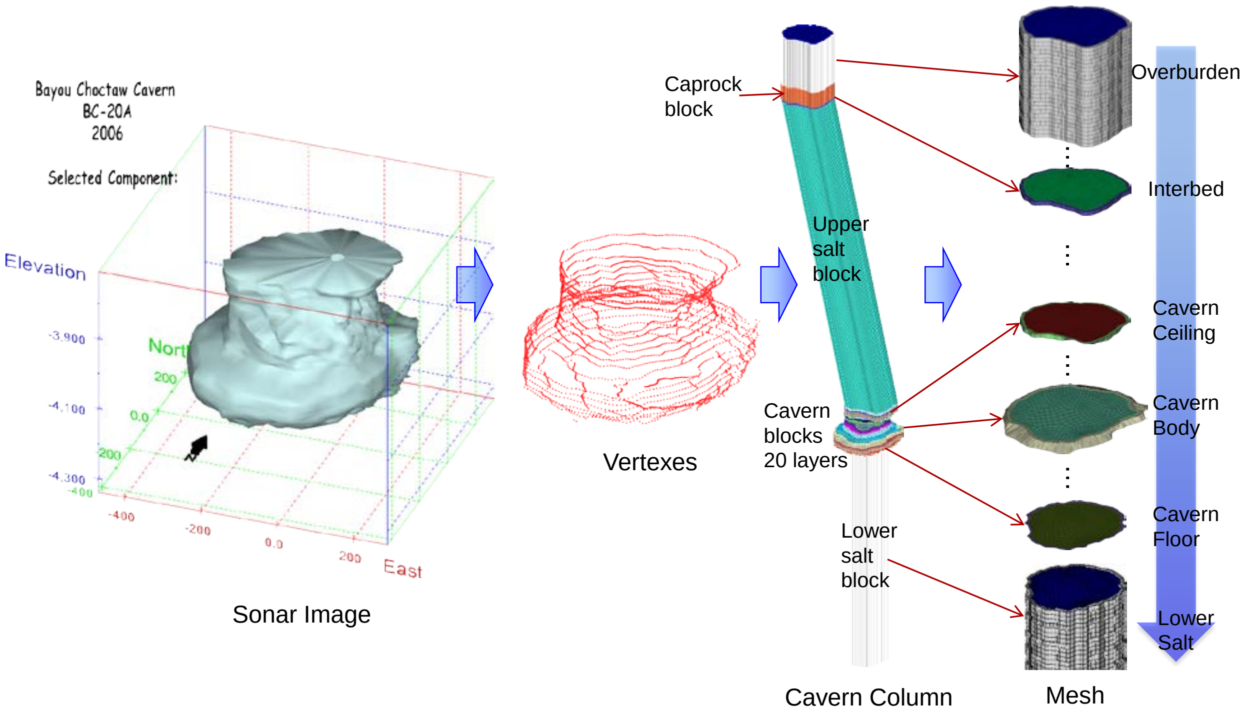


Figure 8: Work flow to create Bayou Choctaw Cavern 20 mesh

4.2.3. Dome

Figure 9 shows the procedure to create the BC dome mesh. The image of the dome boundary such as dome top and flank are obtained from the seismic survey in 1994 [Rautman et al., 2009]. The 3D-coordinates of vertices are resampled from the seismic image. The real interbed between the salt dome and caprock is not flat. The uneven interbed should create poorly shaped elements. To avoid the poor shape, the vertex data above the elevation of -1320 ft are removed (called 'trimming'). The salt dome leans to the west. The coordinates of vertices at every 20 ft element level from elevations -1300 ft through -700 ft are calculated considering the leaning. The dome centers X-, Y-coordinates at elevations -4000 ft and -900 ft are (-62.50, 134.99) and (-782.10, 16.62). The differences between two coordinates DX, DY, and DH are calculated to be 719.61 ft, 118.37 ft, and -3100 ft, respectively. The leaning is calculated using DX, DY, and DH. In similar, the vertices data below the elevation of -5880 ft are removed (trimming). The vertex data for the lower salt blocks are translated vertically downward from the vertex data of the bottom of trimmed salt dome block (-5880 ft). The leaning slope of dome is not considered for the lower salt block.

The dome mesh has to be composed of hexahedral elements. The hexahedral element shape has to be translated from the top through the bottom of the model. Therefore, the overburden block, caprock blocks, interbed block, upper salt blocks, and lower salt blocks have to be generated first. The vertex data for the upper salt blocks are translated upward from the vertex data of the trimmed salt dome top. The upper salt block leans to the west to match the trend of the trimmed salt dome body. The vertex data for the interbed, caprock, and overburden blocks are translated vertically upward from the vertices data of the top of upper salt blocks. 283 dome slice blocks with 20 ft thickness are created using the coordinates of vertices. Finally, the dome column consists of 286 slice blocks including the overburden block 500 ft thick, caprock block 160 ft thick, and bottom salt dome block 100 ft thick.

Each block is punched with 26 cavern columns which were generated in the previous section. The vertices data of each hole in the dome layer blocks are transferred from the cavern columns. The mesh will be created with the vertices of each hole and dome perimeter.

The hexahedral mesh in each block will be translated from over/under block. The cross-section areas of each cavern column and dome column are varied with depth. Considering the cross-sectional areas of the pillars between caverns; caverns and dome edge, the optimum base layer block is selected to avoid creating poor shape elements, so create the number of poor shape elements in every layer block as little as possible. The hexahedral element meshes are created at the base slice block which bottom is located at -2760 ft below the surface with 20 ft thickness. The quadrilateral element shapes on the top of the base slice block translate upward through the top of the dome column, and the element shapes on the bottom of the base layer block translate downward through the bottom of the dome column. 286 meshed layer blocks are assembled into the dome column which consists of 320 element levels (the height of dome column is 6400 ft). The dome leans to the west as shown in Figure 9.

4.2.4. Surrounding rock

Figure 10 shows the procedure to create the BC surrounding rock (far field) mesh. To represent the far field surrounding the BC dome, a rectangular brick, whose widths in E-W and N-S directions are two times the maximum widths of dome in the E-W and N-W directions, respectively, is created at -6400 ft depth. The rectangular brick is the base surrounding rock slice block whose thickness and bottom elevation are 100 ft and -6400 ft, respectively.

The bottom salt dome block, which was created in the previous section, is inserted into the base block and punched with the bottom salt dome block. The vertices data of the dome perimeter are transferred from the salt dome block. The number of intervals on E-W and N-S sides of the block is 20 which is selected as a balance number between the total number of elements and element shape. The number of intervals is one of key factors to determine the total number of elements in the model. Larger number of elements consumes more computer running time, but makes better mesh quality. The hexahedral element mesh is constructed with the vertices and the intervals. The thickness of each element layer sets up 20 ft in this model. The mesh has five element levels vertically because the thickness of the base block is 100 ft.

In the similar manner, a rectangular block is created right above the base block. The top surface of the base block becomes the bottom surface of the new block. The vertices of four corners of the new block top are calculated considering the dome declination because the dome leans to the west. New blocks are constructed over the base block upward to the surface. Each layer block is assembled as the surrounding rock. Four sides of the surrounding rock parallel the declination of the center axis of the dome to maintain the mesh quality.

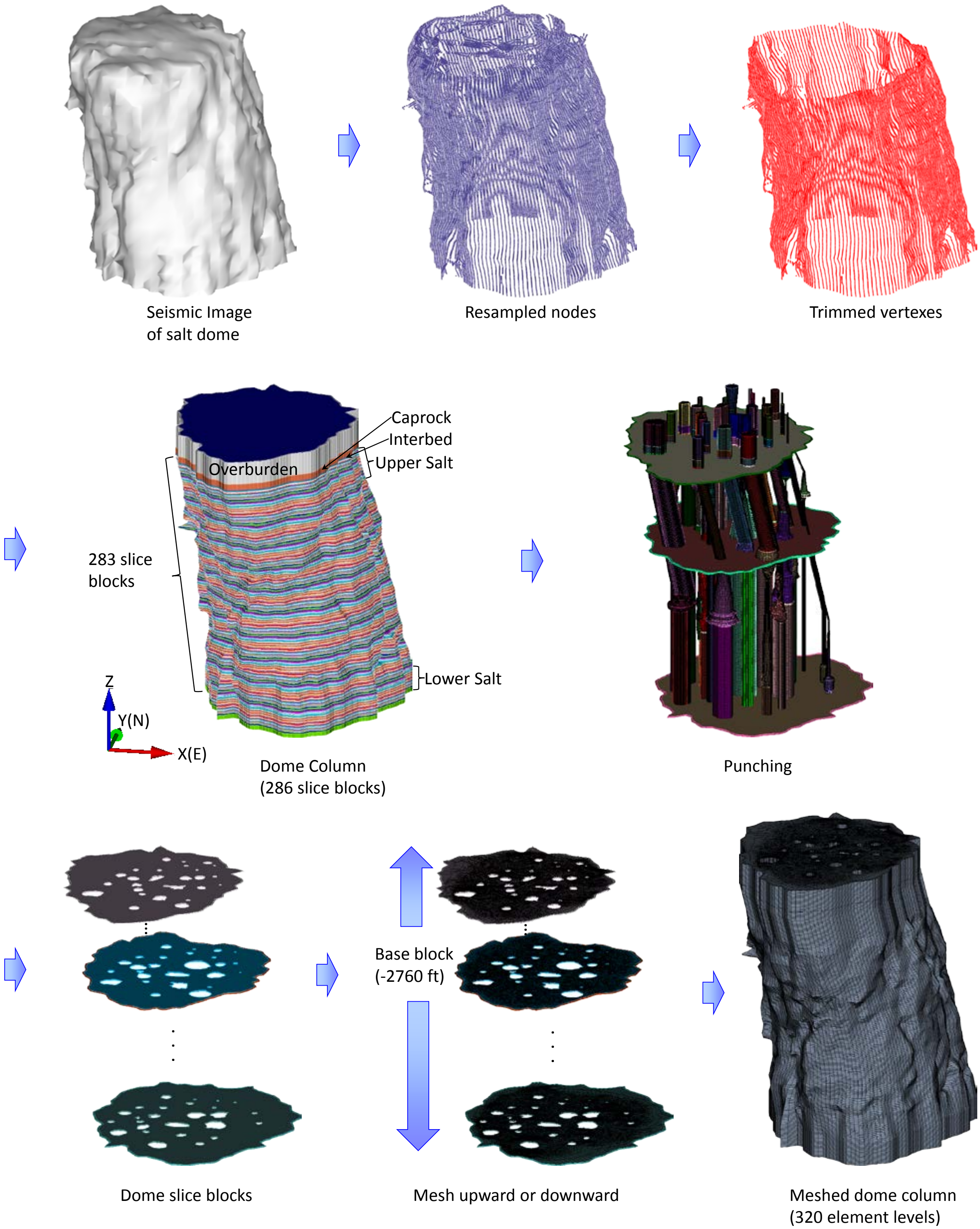


Figure 9: Work flow to create Bayou Choctaw dome mesh

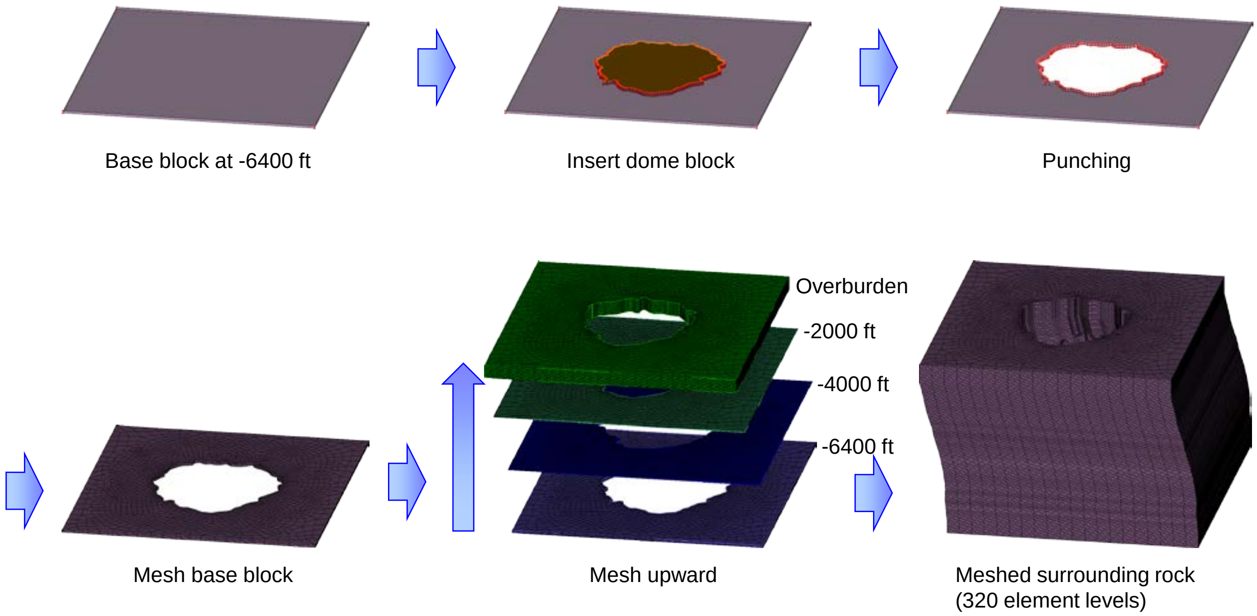


Figure 10: Work flow to create Bayou Choctaw surrounding rock (far field) mesh

5. SONAR DATA RESAMPLING

5.1. Vertical Resampling

Representations of the Bayou Choctaw caverns based on sonar data were incorporated into the geomechanical model to provide a more realistic depiction of the caverns. To facilitate this, the cavern sonar data were resampled to a nodal spacing more appropriate for the geomechanical model. This process was implemented using a custom Python script which operated on ASCII files containing representations of the sonar data. The output from the script was an ASCII file containing X, Y, and Z locations of the newly determined nodal sites. The details of this process are provided below.

The actual sonar data is delivered from the sonar contactors in one of two formats. An additional processing code SONAR7[4] was used to turn these contractor files into a format compatible with the MVS geologic modeling software suite. This is a mature process which has been used for many years at Sandia. This step is necessary to provide a full three-dimensional surface model of the sonar data. The nodal output for the geomechanical simulations needs to be at specific depth intervals which may not correspond to the actual sonar sampling locations. By creating a continuous three-dimensional surface model of the sonar data, we can resample the model at any depth desired.

This general process is shown in Figure 11 which shows a portion of a typical cavern. The left hand image shows the original sonar data as a mesh of three-dimensional points which create a continuous surface. The right hand image shows the same sonar surface overlaid by blue lines representing the desired sampling interval for the geomechanical simulations. This demonstrates how the original sonar data points do not necessarily line up with the desired vertical sampling interval, and how the continuous three-dimensional surface allows sampling at any needed depth.

4 A data conversion program developed by Sandia. SONAR7 converts sonar data sets with various formats provided by different vendors into the extended file format (EFF) and other MVS compatible formats.

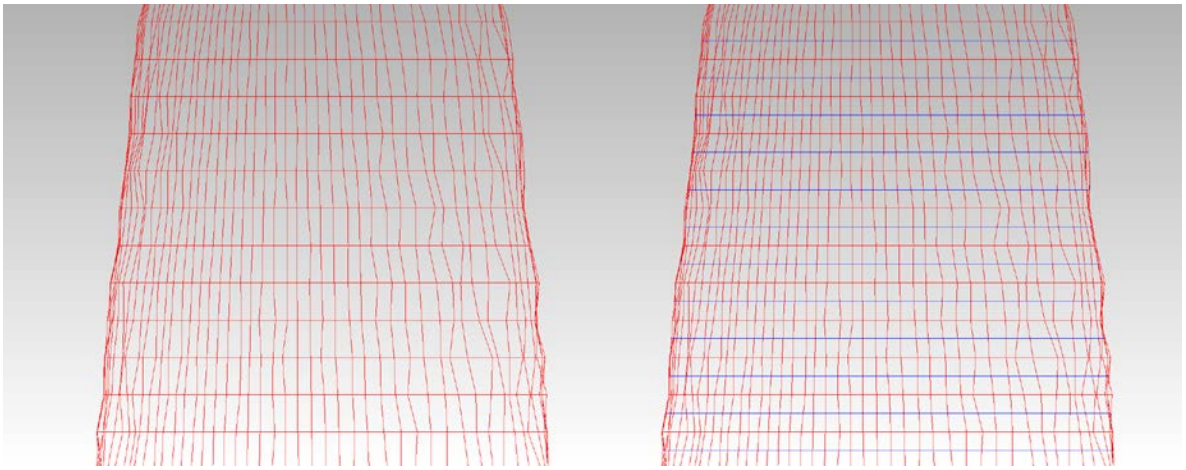


Figure 11: Comparison between original sonar data (left) and desired surface contour sampling shown by blue lines (right)

The blue line in Figure 11 represent contours of the cavern surface falling at the desired depth spacing. An example of this is shown in Figure 12. These contours of the cavern are then forwarded as ASCII files for use in further processing.

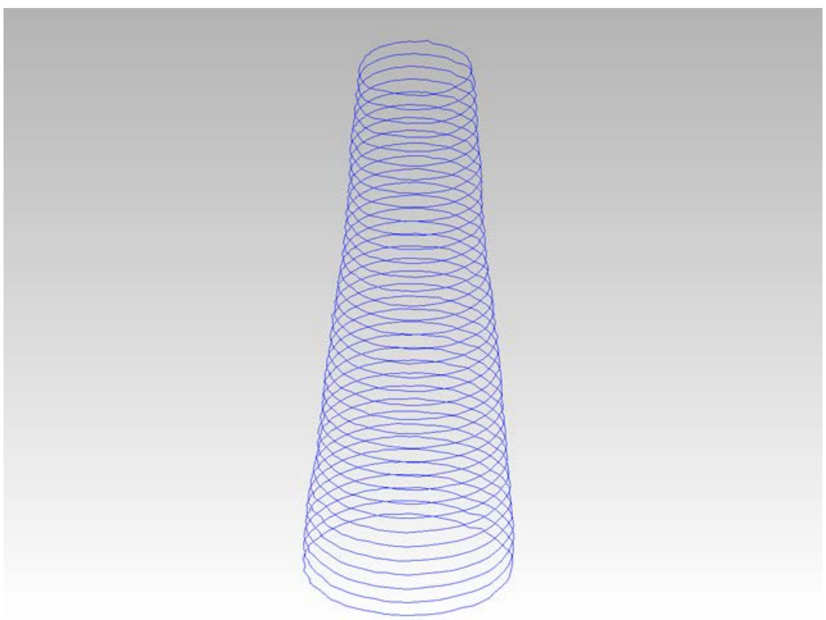


Figure 12: Contours of cavern created from 3D sonar surface

5.2. Horizontal Resampling

With the development of the cavern contour files we now have the cavern sonar data resampled to the necessary depth intervals. Now it is necessary to sub-sample the contours to a desired nodal spacing. For this, each ACII contour file is processed using a custom Python script. The

Python script reads the contour file for a given cavern, then, at a predetermined depth, computes the number of nodes along the contour given a specific nodal spacing. This happens at a specified "template" depth which was chosen to have the circumference necessary to generate the desired number of nodes at an optimal nodal spacing.

Using this template contour as a polygon, the circumference length and desired node spacing is used to compute the total node count for this depth contour. This value is then used to calculate the angular displacement between radial rays originating at the center of the contour polygon, radiating outwards, and intersecting the polygon. These intersections define the locations of the nodes for that depth contour. Figure 13 shows an example of this.

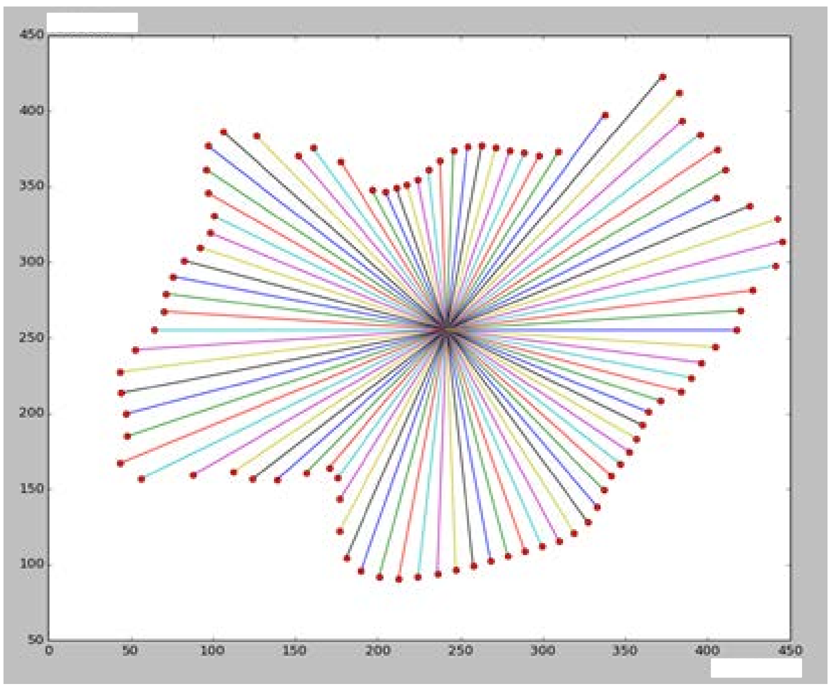


Figure 13: Example of radial rays propagating from center of contour polygon to each circumference nodal location

The process of propagating rays from the center of the contour polygons is repeated for each depth contour. During this process the same nodal count is maintained for each depth level. This allows for the connection of the node locations during the meshing procedure.

An example of the final nodal configuration from this process is shown in Figure 14. These final node locations are then written to an ASCII file for incorporation into the mesh structure for the geomechanical simulation model. A similar process was applied to the three-dimensional geologic model of the Bayou Choctaw salt dome.

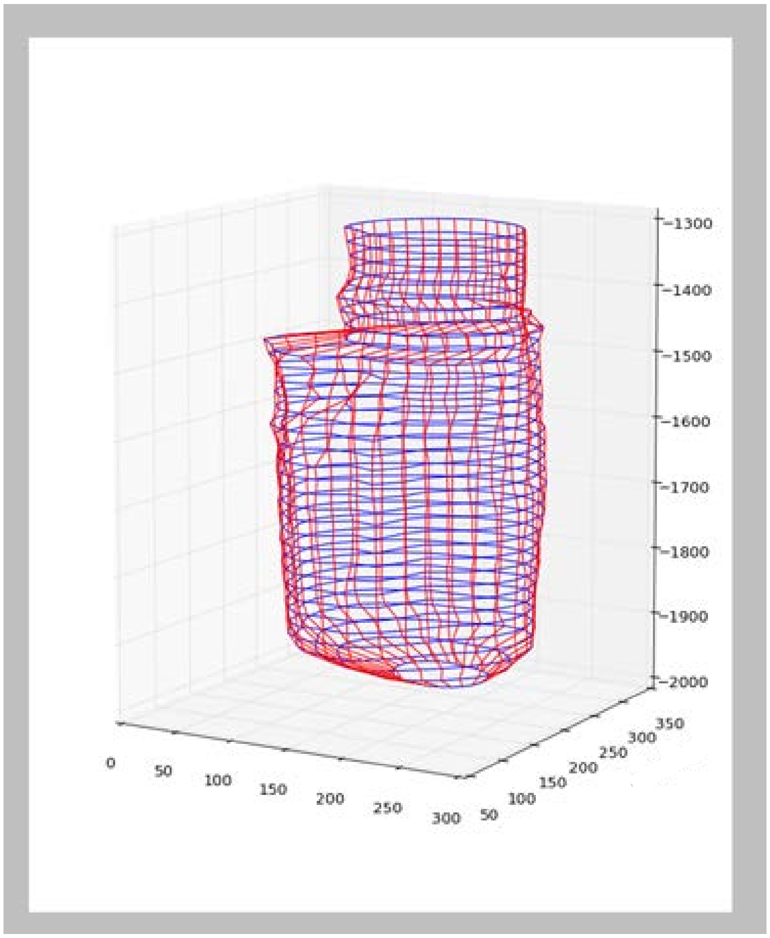


Figure 14: Final node configuration resulting from resampling of cavern sonar data

6. MESH GENERATION

6.1. BC-1

BC-1 is selected to describe the mesh generation procedure for the normal group of non-SPR caverns. The similar methodology is used for other caverns in the group.

6.1.1. Data conversion

Figure 15 shows the sonar image and resampled nodes for BC-1. Each node has X-, Y-, Z-coordinates. The node coordinate data are converted into the vertices data with the Cubit input format through MS Excel manipulation. Figure 16 shows an example spread sheet. The spreadsheet is framed considering the basic rule and equations in Section 4.1. The sheet also contains the macro-algorithm to handle easily the data.

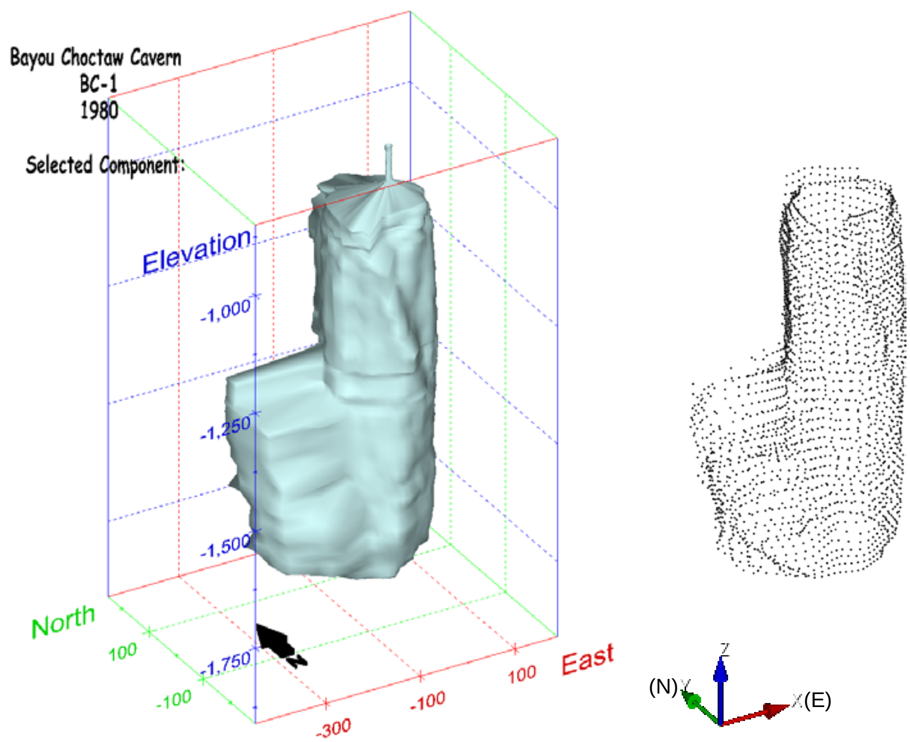


Figure 15: Sonar image (left) and resampled nodes from the sonar image for BC-1

		Vol. Inc. Rate=	15%			1st Drawdown					
		Script	X0	Y0	Z	L0	L1		X1	Y1	Z
surface		Average=	-1143.68	-86.22		1st Drawdown					
		create vertex	-1038.10	-91.19	0.000	105.69	113.35	create vertex	-1030.46	-91.55	0.000
		create vertex	-1032.91	-79.42	0.000	110.98	119.02	create vertex	-1024.89	-78.93	0.000
		create vertex	-1036.83	-68.22	0.000	108.35	116.19	create vertex	-1029.10	-66.92	0.000
		create vertex	-1041.03	-57.45	0.000	106.61	114.32	create vertex	-1033.60	-55.36	0.000
		create vertex	-1049.03	-48.51	0.000	101.89	109.27	create vertex	-1042.18	-45.78	0.000
		create vertex	-1058.84	-41.51	0.000	95.90	102.85	create vertex	-1052.70	-38.27	0.000
		create vertex	-1068.67	-35.81	0.000	90.38	96.92	create vertex	-1063.24	-32.17	0.000
		create vertex	-1078.42	-31.34	0.000	85.27	91.44	create vertex	-1073.69	-27.37	0.000
		create vertex	-1087.31	-27.24	0.000	81.59	87.50	create vertex	-1083.23	-22.97	0.000
		create vertex	-1095.80	-23.63	0.000	78.80	84.51	create vertex	-1092.34	-19.10	0.000
		create vertex	-1103.68	-19.82	0.000	77.52	83.13	create vertex	-1100.78	-15.01	0.000
		create vertex	-1111.43	-16.04	0.000	77.24	82.83	create vertex	-1109.09	-10.96	0.000
		create vertex	-1119.23	-12.24	0.000	77.92	83.56	create vertex	-1117.46	-6.88	0.000
		create vertex	-1127.39	-8.87	0.000	79.05	84.77	create vertex	-1126.21	-3.27	0.000
		create vertex	-1135.91	-5.77	0.000	80.83	86.68	create vertex	-1135.34	0.05	0.000
		create vertex	-1144.88	-2.50	0.000	83.73	89.79	create vertex	-1144.97	3.56	0.000
		create vertex	-1154.58	1.02	0.000	87.92	94.29	create vertex	-1155.37	7.34	0.000
		create vertex	-1165.32	4.93	0.000	93.68	100.46	create vertex	-1166.88	11.53	0.000
		create vertex	-1173.97	-1.66	0.000	89.82	96.32	create vertex	-1176.17	4.46	0.000
		create vertex	-1181.37	-9.24	0.000	85.72	91.92	create vertex	-1184.10	-3.67	0.000
		create vertex	-1190.97	-11.37	0.000	88.53	94.94	create vertex	-1194.39	-5.96	0.000

Figure 16: Cubit batch run resampled node data are converted into vertex data for Cubit input format through Excel spread sheet

6.1.2. Cubit batch files

File 1 shows the Cubit batch run script for BC-1. These command scripts are executed on the Command Prompt Window as shown Figure 17. As the first step, the sub-Cubit journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_sub\`. As the next step, the vertex journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_vtx\`. As the third step, the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou` and then Cubit batch commands are executed.

In the file name of **`bot_0500_surface.jou`** (File 2), **`bot_0500`** indicates the bottom elevation of the block is -500 ft which is the bottom elevation of the overburden layer. **`_surface`** indicates the surface block which top elevation is 0 ft. In the file name of **`bot_0660_above.jou`** (File 4), **`bot_0660`** indicates the bottom elevation of the block is -660 ft which is the bottom elevation of the caprock layer. **`_above`** indicates the block will be created above the cavern. In the file name of **`bot_0680_above.jou`** (File 5), **`bot_0680`** indicates the bottom elevation of the block is -680 ft which is the bottom elevation of the interbed layer. In the file name of **`bot_1040_roof.jou`** (File 6), **`bot_1040`** indicates the bottom elevation of the block is -1040 ft which is the elevation of the cavern ceiling and **`_roof`** indicates the cavern roof block. In the file name of **`bot_1060.jou`** (File 7), **`bot_1060`** indicates the bottom elevation of the block is -1060 ft. In the file name of **`bot_1840_floor.jou`** (File 8), **`bot_1840`** indicates the bottom elevation of the block is -1840 ft which is 20 ft below the cavern floor, at -1820 ft, and **`_floor`** indicates this is a cavern floor block. In the file name of **`bot_6400_below.jou`** (File 9), **`bot_6400`** indicates the bottom elevation of the block is -6400 ft which is the elevation of the model bottom and **`_below`** indicates the block will be created below the cavern. This file naming convention as listed in Table 2 will be applied to other caverns.

File 2 shows the first Cubit command journal file, **bot_0500_surface.jou**, in File 1. **setup.jou** sets up the graphic windows size which default is 1040 (h) x 800 (v) pixels (see File 3). **vtx_0500.jou** creates vertices using the nodal coordinates obtained from resampling sonar data in Section 5.1. **create_vol.jou** creates the volume using the vertices created by **vtx_0500.jou**. **mesh_surface.jou** meshes the volume created by **create_vol.jou**. **save_wo_ns_ss.jou** saves the meshed volume with both Cubit and Genesis formats into the storage. **_wo_ns_ss** indicates the volume is saved without node sets and side sets.

File 4 shows the second Cubit batch command journal file, **bot_0660_above.jou**, in File 1. In the file name of **mesh_above_wo_ss.jou**, **_wo_ss** indicates the volume is meshed without side sets. File 6 through File 9 show the Cubit batch command journal files to create the meshed volumes for the cavern roof, cavern body and wall, cavern floor, and the block below the cavern, respectively. The volumes of cavern roof, wall, and floor are saved with side sets. **save_wo_ss** in **bot_6400_below.jou** indicates the volume below the cavern is saved without side sets but with node set.

As the last step in File 1, the sub-Cubit journal files and vertex journal files are returned to the original storage directories of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\sub\` and `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\vtx\`, respectively, after the construction of 46 meshed slice blocks for BC001 completes.

File 1: Cubit batch run script for BC001

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho bot_0500_surface.jou
Cubit –batch –nographics –noecho bot_0660_above.jou
Cubit –batch –nographics –noecho bot_0680_above.jou
Cubit –batch –nographics –noecho bot_1020_above.jou
Cubit –batch –nographics –noecho bot_1040_roof.jou
Cubit –batch –nographics –noecho bot_1060.jou
Cubit –batch –nographics –noecho bot_1080.jou
Cubit –batch –nographics –noecho bot_1100.jou
Cubit –batch –nographics –noecho bot_1120.jou
Cubit –batch –nographics –noecho bot_1140.jou
Cubit –batch –nographics –noecho bot_1160.jou
Cubit –batch –nographics –noecho bot_1180.jou
Cubit –batch –nographics –noecho bot_1200.jou
Cubit –batch –nographics –noecho bot_1220.jou
Cubit –batch –nographics –noecho bot_1240.jou
Cubit –batch –nographics –noecho bot_1260.jou
Cubit –batch –nographics –noecho bot_1280.jou
Cubit –batch –nographics –noecho bot_1300.jou
Cubit –batch –nographics –noecho bot_1320.jou
Cubit –batch –nographics –noecho bot_1340.jou
Cubit –batch –nographics –noecho bot_1360.jou
Cubit –batch –nographics –noecho bot_1380.jou
Cubit –batch –nographics –noecho bot_1400.jou
Cubit –batch –nographics –noecho bot_1420.jou
Cubit –batch –nographics –noecho bot_1440.jou
Cubit –batch –nographics –noecho bot_1460.jou
Cubit –batch –nographics –noecho bot_1480.jou
Cubit –batch –nographics –noecho bot_1500.jou
Cubit –batch –nographics –noecho bot_1520.jou
Cubit –batch –nographics –noecho bot_1540.jou
Cubit –batch –nographics –noecho bot_1560.jou
Cubit –batch –nographics –noecho bot_1580.jou
Cubit –batch –nographics –noecho bot_1600.jou
Cubit –batch –nographics –noecho bot_1620.jou
Cubit –batch –nographics –noecho bot_1640.jou
Cubit –batch –nographics –noecho bot_1660.jou
Cubit –batch –nographics –noecho bot_1680.jou
Cubit –batch –nographics –noecho bot_1700.jou
Cubit –batch –nographics –noecho bot_1720.jou
Cubit –batch –nographics –noecho bot_1740.jou
Cubit –batch –nographics –noecho bot_1760.jou
Cubit –batch –nographics –noecho bot_1780.jou
Cubit –batch –nographics –noecho bot_1800.jou
Cubit –batch –nographics –noecho bot_1820.jou
Cubit –batch –nographics –noecho bot_1840_floor.jou
Cubit –batch –nographics –noecho bot_6400_below.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\vtx\
```

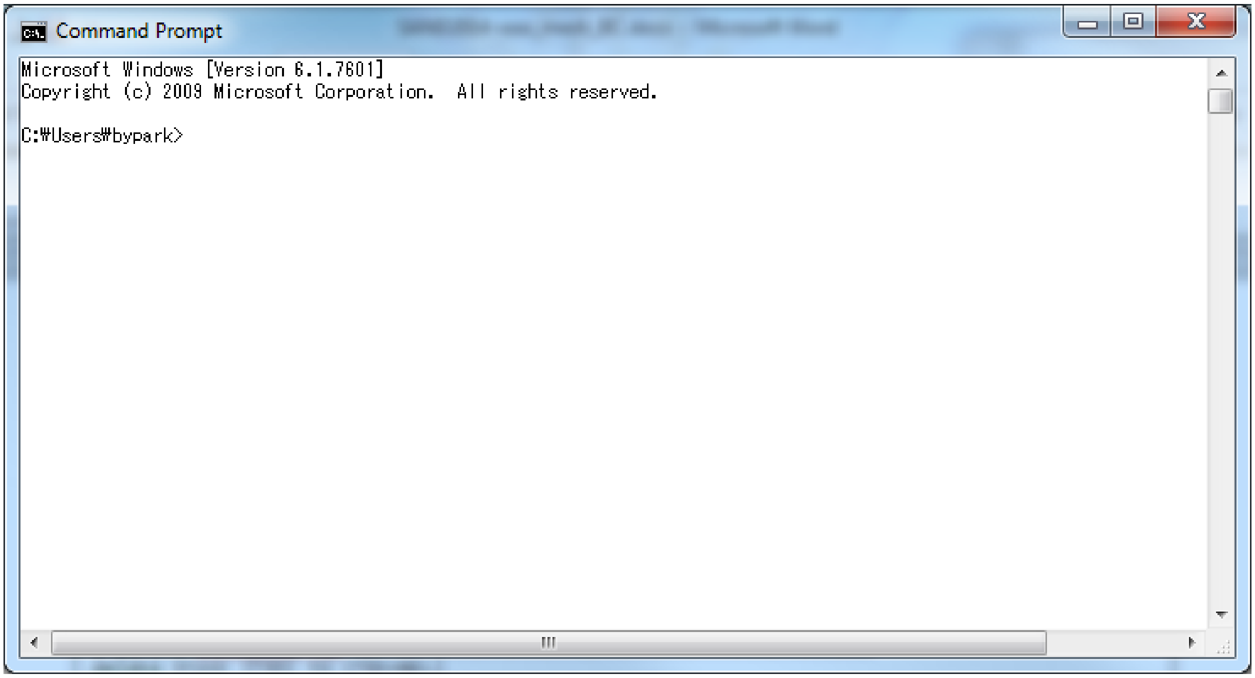


Figure 17: Command Prompt Window

File 2: bot_0500_surface.jou

```
# Graphic Window Size ==============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_0500.jou")}
# Create Volume=====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_surface.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ns_ss.jou")}
#
exit
```

File 3: setup.jou

```
graphic windowsize 1040 800
#graphic windowsize Maximum
#graphic windowsize 1040 1000
```

File 4: bot_0660_above.jou

```
# Graphic Window Size ==============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_0660.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_above_wo_ss.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ns_ss.jou")}
#
exit
```

File 5: bot_0680_above.jou

```
# Graphic Window Size ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_0680.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_above_wo_ss.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ns_ss.jou")}
#
exit
```

File 6: bot_1040_roof.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_1040.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_roof.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 7: bot_1060.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_1060.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 8: bot_1840_floor.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_1840.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_floor.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 9: bot_6400_below.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6400.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_below_wo_ss.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ss.jou")}
#
exit
```

6.1.3. Block in overburden layer

6.1.3.1. Create volumes

File 10 shows the Cubit input journal file to create the vertices for the BC-1 cavern column block in the overburden layer. The elevations of the top and bottom of the block are zero ft and -500 ft, respectively. BC-1 consists of 60 vertices on a perimeter of the cavern wall. As mentioned in Section 3.1, BC-1 considers one onion skin as shown in Figure 18. The coordinate values of the outer perimeter vertices (`Drawdown 1`) in File 10 are calculated using Eq. (4).

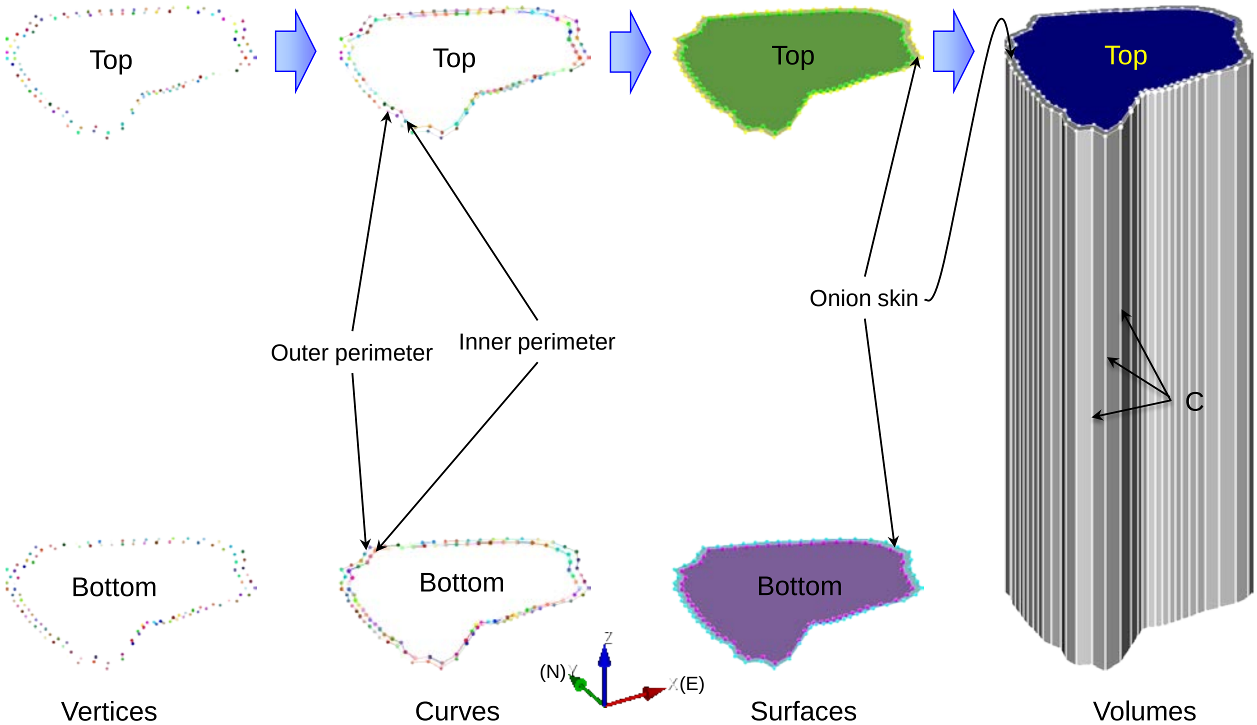


Figure 18: Vertices, curves, surfaces, and volumes of BC-1 column in overburden layer

File 11 shows the journal file of **`create_vol.jou`** in File 2 to create the cavern column block in the overburden layer. Error messages will be recorded into **`bc001_0500.err`** and **`bc001_0500.log`** in the following directory:

`C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\err\`

C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\log\

These scripts make it easy to check when, where, and why an error occurs during Cubit execution. After a series of Cubit batch runs completes (File 1), 46 cavern slice blocks are created. We can check easily which volume the error occurs at among 46 meshed slice blocks created from 46 batch runs.

File 10: vtx_0500.jou

```
# Top elevation       : {TELE=       0      }ft
# Bottom elevation    : {BELE=       -500   }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer    : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19         0
create vertex  -1032.91       -79.42         0
create vertex  -1036.83       -68.22         0
.
.                                                        60 lines     Inner perimeter
.
create vertex  -1050.42       -121.88        0
create vertex  -1047.45       -111.90        0
create vertex  -1045.24       -101.66        0
### Drawdown 1 ----------------------------------                                    Top
create vertex  -1030.46       -91.55         0
create vertex  -1024.89       -78.93         0
create vertex  -1029.10       -66.92         0
.
.                                                                     Outer perimeter
.
create vertex  -1043.67       -124.47        0
create vertex  -1040.48       -113.76        0
create vertex  -1038.12       -102.78        0
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19         -500
create vertex  -1032.91       -79.42         -500
create vertex  -1036.83       -68.22         -500
.
.                                                                     Inner perimeter
.
create vertex  -1050.42       -121.88        -500
create vertex  -1047.45       -111.90        -500
create vertex  -1045.24       -101.66        -500
### Drawdown 1 ----------------------------------                                    Bottom
create vertex  -1030.46       -91.55         -500
create vertex  -1024.89       -78.93         -500
create vertex  -1029.10       -66.92         -500
.
.                                                                     Outer perimeter
.
create vertex  -1043.67       -124.47        -500
create vertex  -1040.48       -113.76        -500
create vertex  -1038.12       -102.78        -500
```

In Cubit, a volume consists of surfaces, and a surface consists of curves, and a curve consists of vertices. One curve is created with two vertices. The top and bottom of inner and outer perimeters of cavern column as shown in Figure 18 consist of 60 curves each created by `create` `curve vertex`. Two surfaces on top and bottom of the column are created with 60 curves through `create surface`. Two volumes are created by `create volume loft surface` through matching the vertices on top and bottom surfaces one by one using `match vertex`. Two volumes are overlapped. To separate two volumes, the outside volume is cut by the surface of the inside volume through `webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}`, and then a cavern column volume and onion skin volume enclosing the cavern column volume are created. The duplicated cavern volume are deleted using `delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}`. During creating volumes, unexpected vertices are created occasionally on curves which connect the top vertices to the bottom vertices (like curves C in Figure 18). The unexpected vertices create unexpected mesh lines which cause skew mesh shape, so they have to be removed through `simplify curve all except curve {TVTX0} to {TNVTX}`. To remove the duplicated geometries such vertex, curve, surface, etc., all geometries are merged through `merge all`. The unnecessary surfaces, which were created during the process, are removed using `delete body 1 to {TNSB}`.

File 11: create_vol.jou

```
Logging Errors on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\err\bc001_"//tostring(-
BELE)//".err")}
Set  logging  on  file  {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\log\bc001_"//tostring(-
BELE)//".log")}
# Create Curve ======================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create curve vertex {TVTX0=VI0*NVTX+1} {TVTX0+1}
create curve vertex {TVTX0+1} {TVTX0+2}
create curve vertex {TVTX0+2} {TVTX0+3}
.
.                                              60 lines     Inner perimeter
.
create curve vertex {TVTX0+57} {TVTX0+58}
create curve vertex {TVTX0+58} {TVTX0+59}
create curve vertex {TVTX0+59} {TVTX0}                                        Top
### Drawdown 1 ---------------------------------
create curve vertex {TVTX1=VI1*NVTX+1} {TVTX1+1}
create curve vertex {TVTX1+1} {TVTX1+2}
create curve vertex {TVTX1+2} {TVTX1+3}
.
.                                                           Outer perimeter
.
create curve vertex {TVTX1+57} {TVTX1+58}
create curve vertex {TVTX1+58} {TVTX1+59}
create curve vertex {TVTX1+59} {TVTX1}
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create curve vertex {BVTX0=(NVOL+VI0)*NVTX+1} {BVTX0+1}
create curve vertex {BVTX0+1} {BVTX0+2}
create curve vertex {BVTX0+2} {BVTX0+3}
.
.                                                           Inner perimeter
.
create curve vertex {BVTX0+57} {BVTX0+58}
create curve vertex {BVTX0+58} {BVTX0+59}
create curve vertex {BVTX0+59} {BVTX0}
### Drawdown 1 ---------------------------------                             Bottom
create curve vertex {BVTX1=(NVOL+VI1)*NVTX+1} {BVTX1+1}
create curve vertex {BVTX1+1} {BVTX1+2}
create curve vertex {BVTX1+2} {BVTX1+3}
.
.                                                           Outer perimeter
.
create curve vertex {BVTX1+57} {BVTX1+58}
create curve vertex {BVTX1+58} {BVTX1+59}
create curve vertex {BVTX1+59} {BVTX1}
# Create Surface ====================================================
Create surface curve {TVTX0}to{TVTX1-1}
Create surface curve {TVTX1}to{BVTX0-1}
Create surface curve {BVTX0}to{BVTX1-1}
Create surface curve {BVTX1}to{TNVTX}
```

(To be continued)

```
# Create Volume ==================================================
### Drawdown 0 (Initial Cavern) -----------------
create volume loft surface {TSI0} {BSI0} \
match vertex {TVTX0} {BVTX0} \
match vertex {TVTX0+1} {BVTX0+1} \
match vertex {TVTX0+2} {BVTX0+2} \
.
.                                                60 lines          cavern column volume
.
match vertex {TVTX0+57} {BVTX0+57} \
match vertex {TVTX0+58} {BVTX0+58} \
match vertex {TVTX0+59} {BVTX0+59}
### Drawdown 1 ---------------------------------
create volume loft surface {TSI1} {BSI1} \
match vertex {TVTX1} {BVTX1} \
match vertex {TVTX1+1} {BVTX1+1} \
match vertex {TVTX1+2} {BVTX1+2} \
.
.                                                                  Skin column volume
.
match vertex {TVTX1+57} {BVTX1+57} \
match vertex {TVTX1+58} {BVTX1+58} \
match vertex {TVTX1+59} {BVTX1+59}
## Create onion skin volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}
#
delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}
### remove the vertices on the curves BEtween the top and bottom
simplify curve all except curve      {TVTX0} to {TNVTX}
merge all  # to remove unnecessary vertices
delete body 1 to {TNSB}
```

6.1.3.2. Mesh volumes

File 12 shows the Cubit command scripts to create mesh in the volume constructed in the previous section. `define_group_1skin.jou` (File 13) is executed to group specific curves and surfaces as described in Section 3.4.

Figure 19 shows the steps to create mesh into the volume. The top surface of the inner volume (`Drawdown 0`) is meshed using the following scripts:

```
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
```

The key methodologies in the mesh process are:

- More than one mesh lines have to be created at each vertex (`type side`) to prevent creating a negative quadrilateral shape of element.
- Mesh line does not have to be created in the curve between two vertices (`interval 1`) to control the mesh shape.

Figure 20 shows the top surface of the inner cavern column in the overburden layer and the surface at elevation -1360 ft. The shapes of horizontal cross-section at elevations zero and -1360 ft are pretty different, because the area and shape of a cavern cross-section varies with depth. The surface at zero elevation is meshed with `interval 1` without `type side` options (left in Figure 20). To keep the hexahedral element shape, a vertex on the top surface has to be connected to the corresponding vertex on the bottom of model one to one. Each vertex #1 through #60 on the zero elevation cross-section corresponds to vertex #1 through #60, respectively, on the cross-section of elevation -1360 ft. The quadrilateral composed of vertices 21, 22, 23, and P at zero elevation becomes a negative quadrilateral at elevation -1360 ft. The quadrilateral composed of vertices 37, 38, 39, and Q at zero elevation becomes a poorly shaped quadrilateral at elevation -1360 ft. The quadrilateral composed of vertices 39, 40, 41, and Q at zero elevation becomes a poorly shaped quadrilateral at -1360 ft. That means a positive quadrilateral mesh at zero elevation could be a negative at a different elevation. A negative quadrilateral facet cannot make a positive hexahedral element.

To avoid the negative quadrilateral, the option `type side` is used. Figure 21 shows the meshed surfaces with the option `type side` at elevations zero and -1360 ft, respectively. One mesh line is created at vertices 18, 38, and 40 each, and two mesh lines are created at vertex 22 (left in Figure 21). Then, element facets containing vertices 18, 22, 38, and 40 are not poor shape of quadrilateral at elevation -1360 ft (right in Figure 21), i.e. normal hexahedral elements are created at elevation -1360 ft translating from the surface elements.

To improve the mesh quality, “smoothing” steps are conducted until no smoothing is needed with the following scripts.

```
#### Smoothing ------------------------
surface in sdl0t smooth scheme cond
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
```

The top surface of the outside volume (Drawdown 1) is meshed through the following scripts:

```
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1
mesh surface in sdl1t
```

To prevent creating skewed mesh, `scheme hole rad_intervals 1` is applied.

The vertical curves on the volume are divided by 20 ft then 25 element levels are created because the thickness of the overburden layer is 500 ft. Then, the volumes are meshed entirely with the meshed horizontal sections and vertical curves.

File 12: mesh_surface.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ===============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
#### Smoothing ------------------------
surface in sdl0t smooth scheme cond
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
### Drawdown 1 ---------------------------------
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1 # keep interval 1 to avoid skewed mesh
mesh surface in sdl1t
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one element level = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
# Define Blocks ======================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
```

File 13: define_group_1skin.jou

```
## Define group ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
group "tcurv" add curve in volume all with z_coord > {TELE-1}
group "bcurv" add curve in volume all with z_coord < {BELE+1}
group "tsurf" add surface in volume all with z_coord > {TELE-1}
group "bsurf" add surface in volume all with z_coord < {BELE+1}
group "msurf" add surface in volume all
group "msurf" remove surface in tsurf
group "msurf" remove surface in bsurf
### Drawdown 0 (Initial Cavern) ------------------
#### Curves on outside wall of the volume
group "cdl0w" add curve in volume {VDL0}
group "cdl0w" remove curve in tcurv
group "cdl0w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl0t" add surface in volume {VDL0}
group "sdl0t" remove surface in msurf
group "sdl0t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl0w" add surface in volume {VDL0}
group "sdl0w" remove surface in tsurf
group "sdl0w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl0b" add surface in volume {VDL0}
group "sdl0b" remove surface in msurf
group "sdl0b" remove surface in tsurf
### Drawdown 1 ---------------------------------
#### Curves on outside wall of the volume
group "cdl1w" add curve in volume {VDL1}
group "cdl1w" remove curve in volume {VDL0}
group "cdl1w" remove curve in tcurv
group "cdl1w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl1t" add surface in volume {VDL1}
group "sdl1t" remove surface in msurf
group "sdl1t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl1w" add surface in volume {VDL1}
group "sdl1w" remove surface in volume {VDL0}
group "sdl1w" remove surface in tsurf
group "sdl1w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl1b" add surface in volume {VDL1}
group "sdl1b" remove surface in msurf
group "sdl1b" remove surface in tsurf
### Skin for webcut = {skn=VDL1} ----------------
```

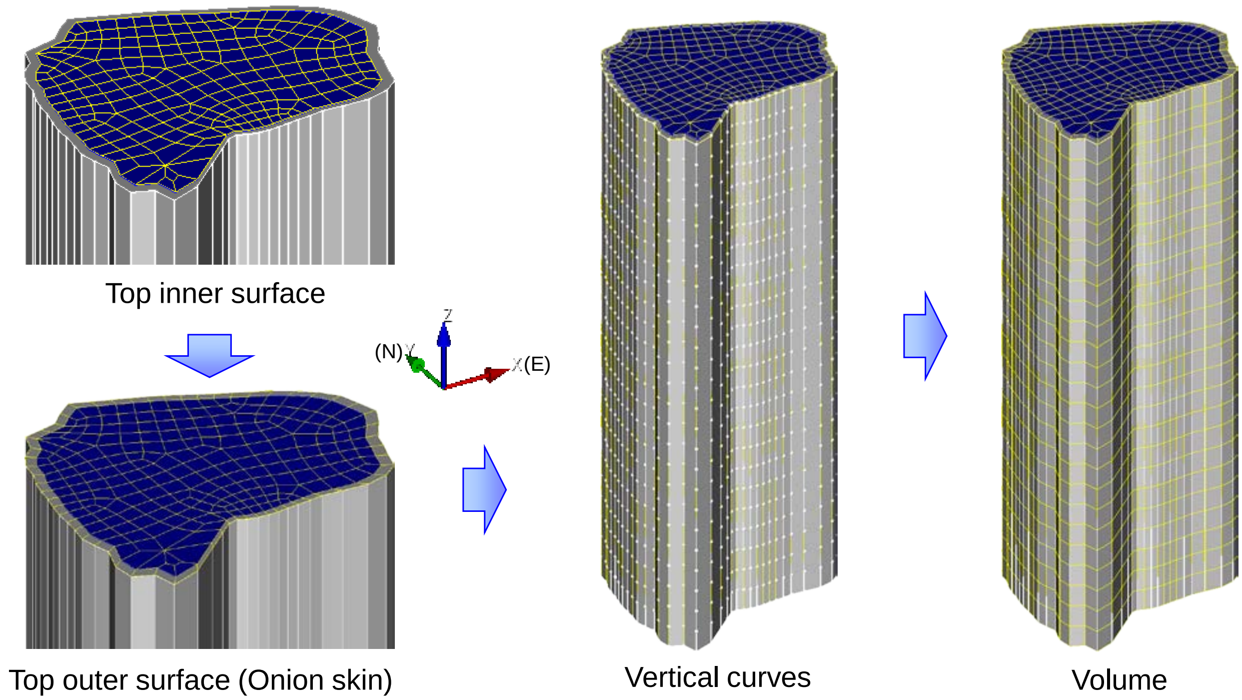


Figure 19: Steps to create mesh into BC-1 cavern column in overburden layer

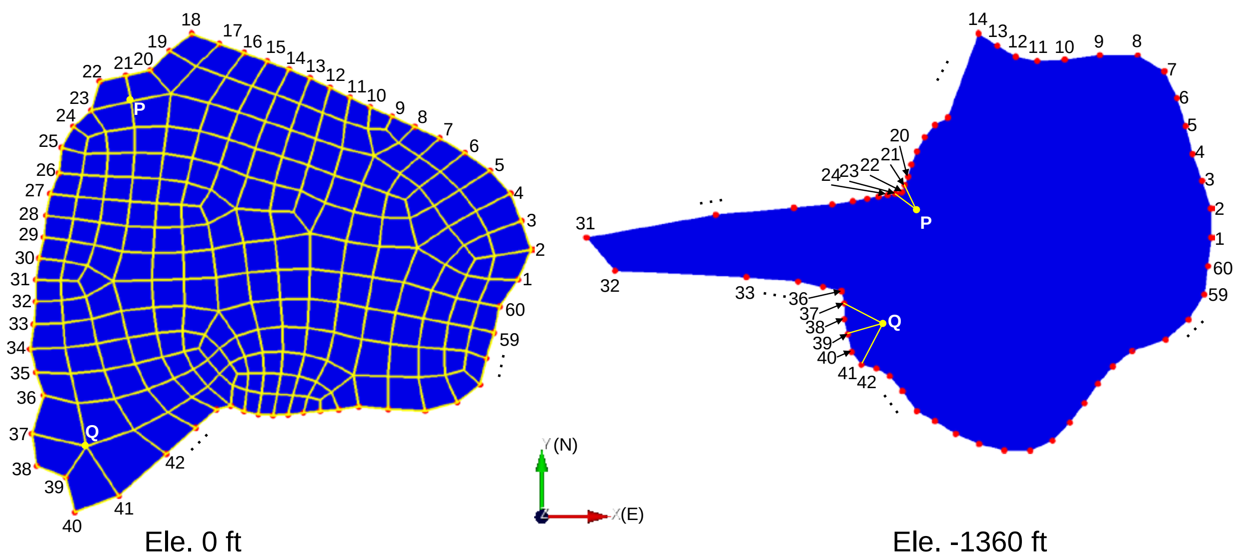


Figure 20: Cross-section surface of the inner cavern column volume at elevations of 0 ft and -1360 ft

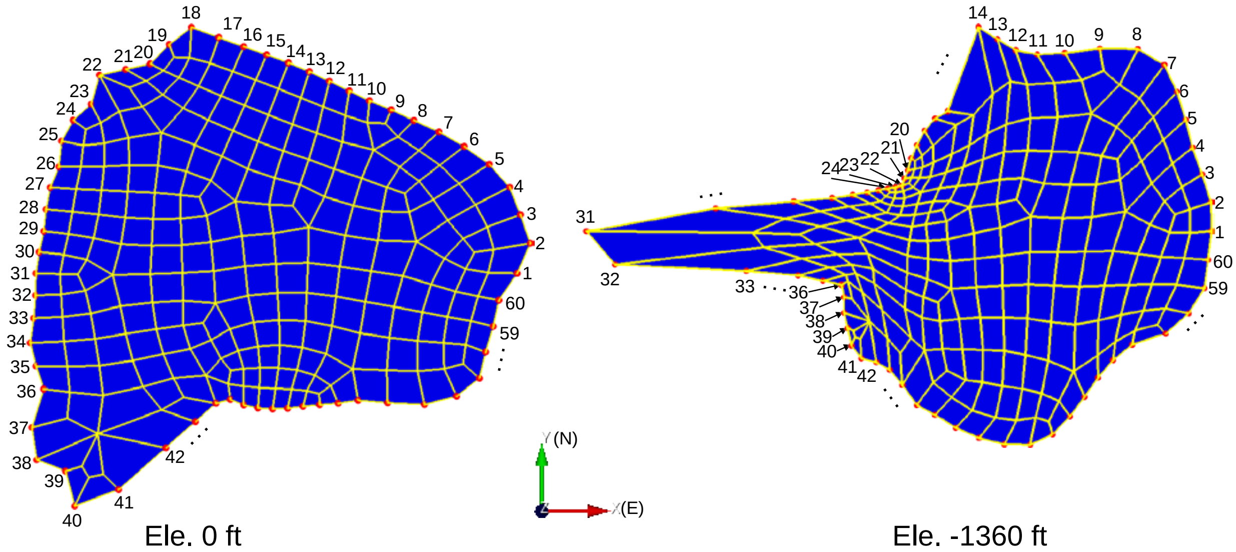


Figure 21: Meshed surfaces with option “type side” at elevations of 0 ft and -1360 ft

6.1.3.3. Save volumes

File 14 shows the Cubit journal command file to save the meshed volume into the storage. The Cubit output (**bc001_500.cub**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\`, and the Genesis file (**bc001_500.g0**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\g0\`. The abstract file (**bc001_500.abs**) shows the mesh information such as the mesh quality; and numbers of side sets, node sets, elements, and nodes, etc. The abstract file will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\`. The onion skin volume (**bc001_500_skn.cub**) will be saved into the same directory for the Cubit output. The onion skin volume will be used for punching the dome slice volume in the overburden layer to make BC-1 column hole.

File 14: save_wo_ns_ss.jou

```
# Save ============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_"//tostring(-
BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\g0\bc001_"//tostring(-
BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_abstract.txt")}
resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-BELE)//".cub")}
overwrite
set logging off
echo on
delete block all
delete volume all except {skn}
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-
BELE)//"_skn.cub")} overwrite
```

6.1.4. Block in caprock and interbed layer

6.1.4.1. Create volumes

`bot_0660.jou` (File 15) is the Cubit journal file to create the vertices for the BC-1 cavern column volumes in the caprock layer 160 ft thick. The elevations of the top and bottom of the block are -500 ft and -660 ft, respectively. The X- and Y- coordinates are the same as the vertices for the BC-1 cavern column block in the overburden layer because they are constructed vertically with the same horizontal cross-section. Figure 22 shows the steps to create the block. `create_vol.jou` (File 11) is used to create the block which consists of the inner and outer volumes.

`bot_0680_above.jou` (File 16) is the Cubit command journal file to create the vertices for the BC-1 cavern column block in the interbed layer 20 ft thick. The elevations of the top and bottom of the block are -660 ft and -680 ft, respectively. Figure 23 shows the steps to create the block in the interbed layers. In the same manner, `create_vol.jou` (File 11) is used to create the block.

File 15: vtx_0660.jou

```
# Top elevation        : {TELE=       -500    }ft
# Bottom elevation     : {BELE=       -660    }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches   : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19          -500
create vertex  -1032.91       -79.42          -500
create vertex  -1036.83       -68.22          -500
.
.
.
create vertex  -1050.42       -121.88         -500
create vertex  -1047.45       -111.90         -500
create vertex  -1045.24       -101.66         -500
### Drawdown 1 ---------------------------------
create vertex  -1030.46       -91.55          -500
create vertex  -1024.89       -78.93          -500
create vertex  -1029.10       -66.92          -500
.
.
.
create vertex  -1043.67       -124.47         -500
create vertex  -1040.48       -113.76         -500
create vertex  -1038.12       -102.78         -500
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19          -660
create vertex  -1032.91       -79.42          -660
create vertex  -1036.83       -68.22          -660
.
.
.
create vertex  -1050.42       -121.88         -660
create vertex  -1047.45       -111.90         -660
create vertex  -1045.24       -101.66         -660
### Drawdown 1 ---------------------------------
create vertex  -1030.46       -91.55          -660
create vertex  -1024.89       -78.93          -660
create vertex  -1029.10       -66.92          -660
.
.
.
create vertex  -1043.67       -124.47         -660
create vertex  -1040.48       -113.76         -660
create vertex  -1038.12       -102.78         -660
```

60 lines

Inner perimeter

Top

Outer perimeter

Inner perimeter

Bottom

Outer perimeter

File 16: vtx_0680.jou

```
# Top elevation         : {TELE=       -660    }ft
# Bottom elevation      : {BELE=       -680    }ft
# Cavern ID     : {CID=001*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19         -660
create vertex  -1032.91       -79.42         -660
create vertex  -1036.83       -68.22         -660
.
.                                                     60 lines      Inner perimeter
.
create vertex  -1050.42       -121.88        -660
create vertex  -1047.45       -111.90        -660
create vertex  -1045.24       -101.66        -660
### Drawdown 1 ----------------------------------                                      Top
create vertex  -1030.46       -91.55         -660
create vertex  -1024.89       -78.93         -660
create vertex  -1029.10       -66.92         -660
.
.                                                                   Outer perimeter
.
create vertex  -1043.67       -124.47        -660
create vertex  -1040.48       -113.76        -660
create vertex  -1038.12       -102.78        -660
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19         -680
create vertex  -1032.91       -79.42         -680
create vertex  -1036.83       -68.22         -680
.
.                                                                   Inner perimeter
.
create vertex  -1050.42       -121.88        -680
create vertex  -1047.45       -111.90        -680
create vertex  -1045.24       -101.66        -680
### Drawdown 1 ----------------------------------                                      Bottom
create vertex  -1030.46       -91.55         -680
create vertex  -1024.89       -78.93         -680
create vertex  -1029.10       -66.92         -680
.
.                                                                   Outer perimeter
.
create vertex  -1043.67       -124.47        -680
create vertex  -1040.48       -113.76        -680
create vertex  -1038.12       -102.78        -680
```

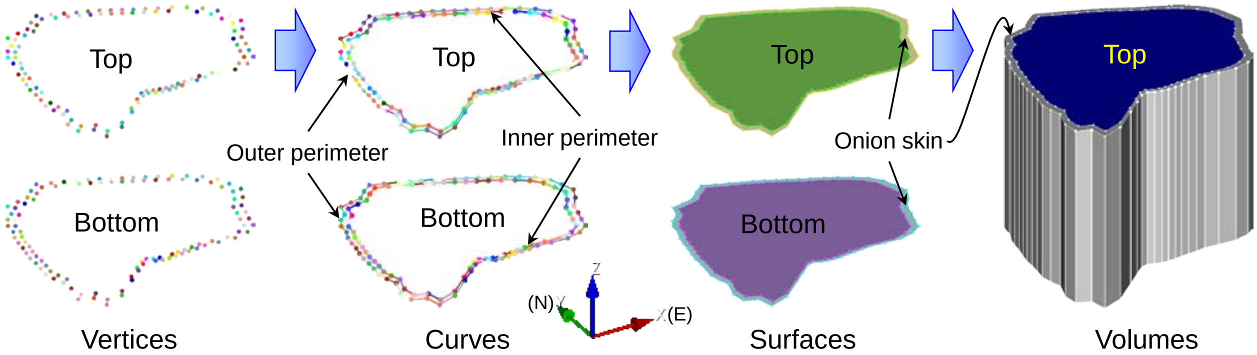


Figure 22: Vertices, curves, surfaces, and volumes of BC-1 column in caprock layer

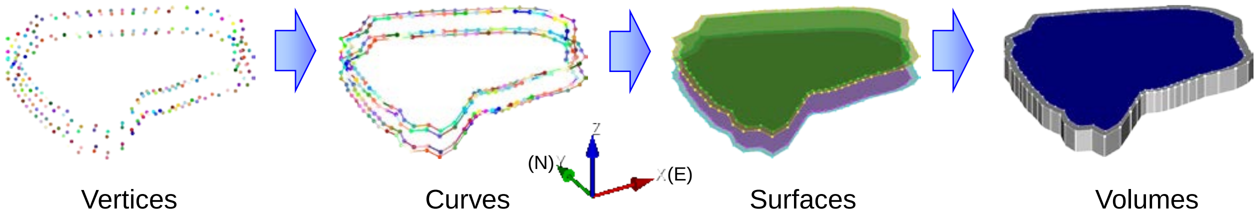


Figure 23: Vertices, curves, surfaces, and volumes of BC-1 column in interbed layer

6.1.4.2. Mesh and save volumes

File 17 shows the command journal file to mesh the volumes in the caprock layer. To create the mesh on the top of the volumes, the meshed volumes (**`bc001_500.cub`**) in the overburden layer is imported from the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\`.The volumes in the caprock layer and the imported volumes are merged. Then the surfaces on the bottom of imported volumes become the surfaces on the top of the volumes in the caprock layer.

The vertical curves on the volumes in the caprock layer are divided by 20 ft, and then 8 element levels are created. The meshes on the top of the volumes are translated to the bottom of the volumes with the following script:

```
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b
sweep_smooth Auto  sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ----------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b
sweep_smooth Auto  sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
```

The unnecessary volumes are deleted, and the meshed inner and outer volume are defined with `Element Block ID` to be used in the assemble stage.

To save the meshed volumes, the same command journal file (File 14) used for the overburden layer is used.

File 17: mesh_above_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ---------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
```

6.1.5. Upper salt block

File 18 shows the Cubit journal file to create the vertices for the BC-1 cavern column block between the interbed layer and cavern roof. The elevations of the top and bottom of the block are -680 ft and -1020 ft, respectively. The X- and Y- coordinates on the top are not the same as those on the bottom because the cavern column leans to the west to be parallel to the dome edge. To create the cavern column volumes, the same file **`create_vol.jou`** as shown in File 11 is used. In the same manner, the cavern column volumes are created as shown Figure 24.

To create the mesh in the block, File 17 (**`mesh_above_wo_ss.jou`**) is used as described in the previous section. The vertical curves on the volumes in the upper salt block are divided by 20 ft, and then 17 element levels are created. The meshes on the top of the volumes are transferred from the bottoms of interbed volumes through the merge step. The meshes are translated to the bottom of the volumes.

The unnecessary volumes are deleted and the meshed inner and outer volumes are defined. The meshed upper salt block is saved through the command scripts in File 14 used for the overburden layer.

File 18: vtx_1020.jou

```
# Top elevation        : {TELE=       -680    }ft
# Bottom elevation     : {BELE=       -1020   }ft
# Cavern ID     : {CID=001*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume    : {VDL0=TNSB+1}
# created 1st drawdown skin volume      : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ===================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -1038.10       -91.19         -680
create vertex  -1032.91       -79.42         -680
create vertex  -1036.83       -68.22         -680
.
.                                                     60 lines     Inner perimeter
.
create vertex  -1050.42       -121.88        -680
create vertex  -1047.45       -111.90        -680
create vertex  -1045.24       -101.66        -680
### Drawdown 1 ----------------------------------                                      Top
create vertex  -1030.46       -91.55         -680
create vertex  -1024.89       -78.93         -680
create vertex  -1029.10       -66.92         -680
.
.                                                                  Outer perimeter
.
create vertex  -1043.67       -124.47        -680
create vertex  -1040.48       -113.76        -680
create vertex  -1038.12       -102.78        -680
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -973.22        -67.80         -1020
create vertex  -968.03        -56.03         -1020
create vertex  -971.95        -44.84         -1020
.
.                                                                  Inner perimeter
.
create vertex  -985.54        -98.50         -1020
create vertex  -982.57        -88.52         -1020
create vertex  -980.36        -78.28         -1020
### Drawdown 1 ----------------------------------                                      Bottom
create vertex  -965.58        -68.16         -1020
create vertex  -960.01        -55.54         -1020
create vertex  -964.22        -43.53         -1020
.
.                                                                  Outer perimeter
.
create vertex  -978.79        -101.08        -1020
create vertex  -975.60        -90.37         -1020
create vertex  -973.24        -79.39         -1020
```

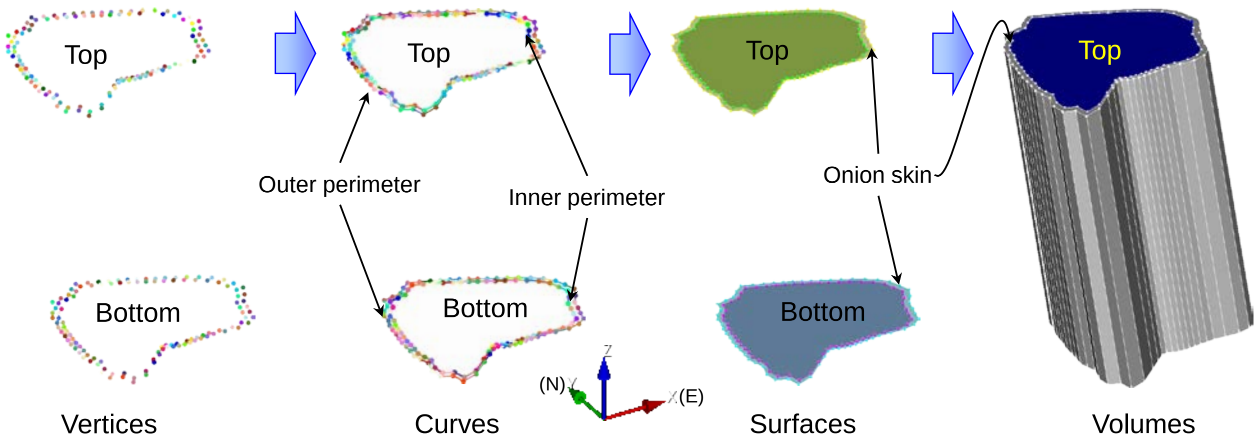


Figure 24: Vertices, curves, surfaces, and volumes of BC-1 column between interbed and roof

6.1.6. Roof block

The Cubit journal file **`bot_1040_roof.jou`** (File 6) creates the volumes for the cavern roof. File 19 shows the Cubit journal file to create the vertices for the BC-1 cavern roof block. The elevations of the top and bottom of the roof block are -1020 ft and -1040 ft, respectively. The cavern roof volumes are created using **`create_vol.jou`** (File 11) as shown Figure 25.

To create the mesh in the volumes, File 20 (**`mesh_roof.jou`**) is used. Figure 26 shows the steps to create the mesh into the cavern roof. As the first step, the upper salt block is imported over the cavern roof block, and the bottom surfaces of the upper salt block and the top surfaces of the roof block are merged to transfer the mesh. As the next step, the vertical curves on the roof block are meshed with one interval because the thickness of the roof block is 20 ft, and then the volumes in the roof block are meshed fully. As the third step, the imported upper salt block is deleted. As the last step, the side set is defined on the bottom of the roof block as `Sideset 11040` to represent the ceiling of the cavern.

The meshed inner and outer volumes are defined as `Element Block 11040` and `Element Block 11041`, respectively. The meshed upper salt block is saved through the command scripts in File 21 (**`save.jou`**) used for the overburden layer.

File 19: vtx_1040.jou

```
# Top elevation       : {TELE=       -1020   }ft
# Bottom elevation    : {BELE=       -1040   }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -973.22        -67.80         -1020
create vertex  -968.03        -56.03         -1020
create vertex  -971.95        -44.84         -1020
.
.                                                    60 lines      Inner perimeter
.
create vertex  -985.54        -98.50         -1020
create vertex  -982.57        -88.52         -1020
create vertex  -980.36        -78.28         -1020
### Drawdown 1 ----------------------------------                                 Top
create vertex  -965.58        -68.16         -1020
create vertex  -960.01        -55.54         -1020
create vertex  -964.22        -43.53         -1020
.
.                                                                  Outer perimeter
.
create vertex  -978.79        -101.08        -1020
create vertex  -975.60        -90.37         -1020
create vertex  -973.24        -79.39         -1020
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -973.22        -67.80         -1040
create vertex  -968.03        -56.03         -1040
create vertex  -971.95        -44.84         -1040
.
.                                                                  Inner perimeter
.
create vertex  -985.54        -98.50         -1040
create vertex  -982.57        -88.52         -1040
create vertex  -980.36        -78.28         -1040
### Drawdown 1 ----------------------------------                                 Bottom
create vertex  -965.58        -68.16         -1040
create vertex  -960.01        -55.54         -1040
create vertex  -964.22        -43.53         -1040
.
.                                                                  Outer perimeter
.
create vertex  -978.79        -101.08        -1040
create vertex  -975.60        -90.37         -1040
create vertex  -973.24        -79.39         -1040
```

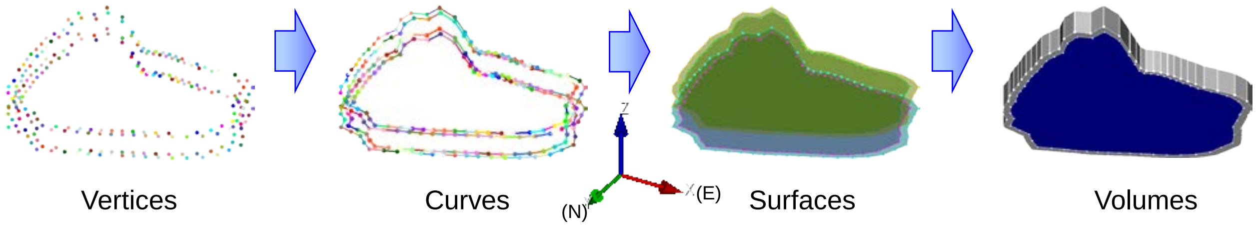


Figure 25: Vertices, curves, surfaces, and volumes of BC-1 column at roof

File 20: mesh_roof.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Sideset ==================================================
sideset {BID+VI0} surface in sdl0b wrt volume {VDL0}
```

File 21: save.jou

```
# Save ============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_"//tostring(-
BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\g0\bc001_"//tostring(-
BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_abstract.txt")}
resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-BELE)//".cub")}
overwrite
set logging off
echo on
delete volume all except {skn}
delete block all
delete sideset all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-
BELE)//"_skn.cub")} overwrite
```

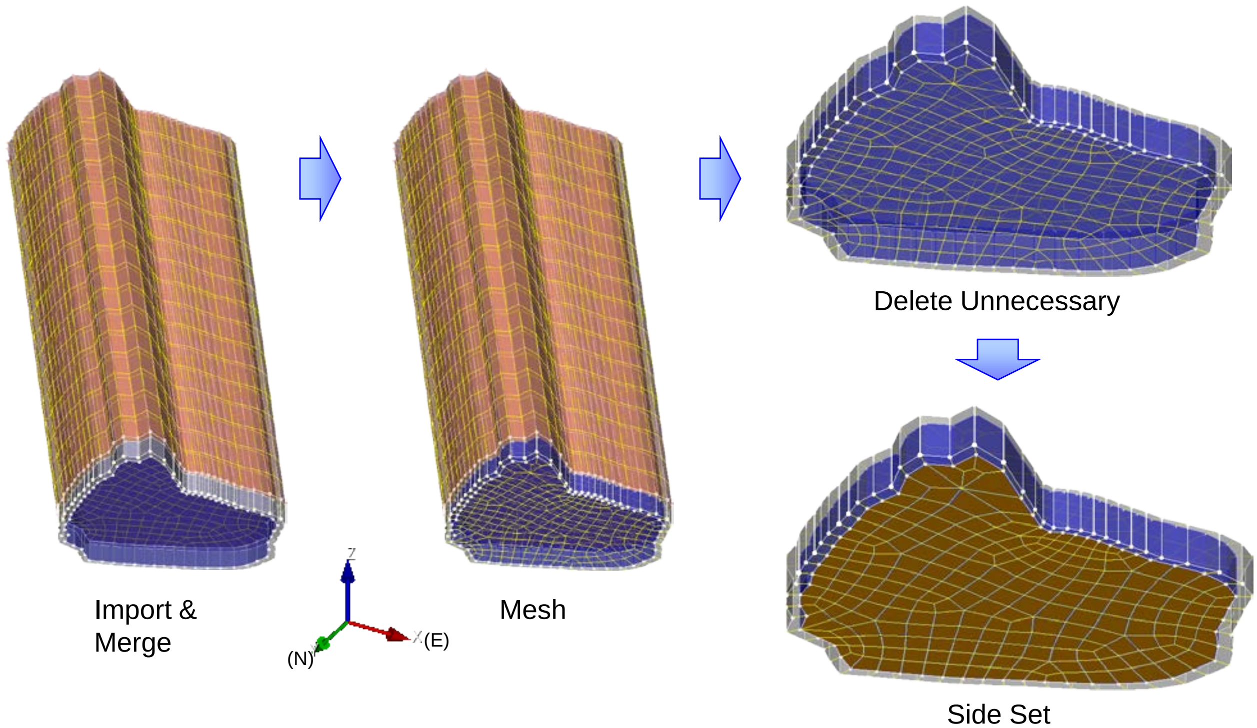


Figure 26: Steps to mesh BC-1 cavern roof whose bottom elevation is -1040 ft

6.1.7. Cavern slice blocks

The BC-1 inside cavern block consists of 39 cavern slice volumes with 20 ft thickness because the elevations of the top and bottom of the block are -1040 ft and -1820 ft, respectively. The first BC-1 cavern slice volume under the roof is created through the Cubit journal file in File 7.

`vtx_1060.jou` is shown File 22. The X- and Y- coordinates of the vertices on the top are not the same as on the bottom because the surface shapes of the top and bottom are different, i.e. the horizontal cross section of the cavern varies with depth.

To create a cavern volume slice inside the cavern, the journal file of **`create_vol.jou`** (File 11) is used as when the previous volumes are created. The top and bottom of inner and outer perimeters of the cavern volume slice as shown in Figure 27 consist of 60 curves each created by `create curve vertex`. Two surfaces on top and bottom of the slice are created with 60 curves through `create surface`. Two volumes are created by `create volume loft surface` through matching the vertices on top and bottom surfaces one by one using `match vertex`. Two volumes are overlapped. To separate two volumes, the outside volume is cut by the side surface of the inside volume through `webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}`, and then an inner slice volume and onion skin slice volume are created. The duplicated cavern volume are deleted using `delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}`. During creating volumes, unexpected vertices as shown in Figure 27 are generated occasionally on the vertical curves which connect the top vertices to the bottom vertices. The unexpected vertices generate unexpected mesh lines which cause skew mesh shape, so they have to be removed through `simplify curve all except curve {TVTX0} to {TNVTX}`. To remove the duplicated geometries such as vertex, curve, surface, etc., all geometries are merged through `merge all`. The unnecessary surfaces generated during the process are removed using `delete body 1 to {TNSB}`. Other 38 cavern slice volumes are created through the same steps in File 22 and File 11.

To create the mesh in the volumes, File 23 (**mesh_wall.jou**) is used. Figure 28 shows the steps to mesh BC-1 cavern slice volume. As the first step, the roof block is imported over the cavern slice volume. The bottom surfaces of the roof block and the top surfaces of the slice volume are merged to transfer the mesh. As the next step, the curves on the wall of the slice volumes are meshed with one interval because the thickness of the slice volumes is 20 ft, and then the volumes in the slice block are meshed fully. As the third step, the imported roof block is deleted. As the last step, the side set is defined as `Sideset 11060` on the inside of outer slice volume to represent the cavern wall. Other 38 cavern slice blocks are meshed through the same steps in File 23.

The meshed inner and outer volumes are defined as `Element Block 11060` and `Element Block 11061`, respectively. The meshed cavern slice volumes are saved through the command scripts in File 21 (**save.jou**) used for the cavern roof block.

File 22: vtx_1060.jou

```
# Top elevation       : {TELE=       -1040   }ft
# Bottom elevation    : {BELE=       -1060   }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -973.22        -67.80         -1040
create vertex  -968.03        -56.03         -1040
create vertex  -971.95        -44.84         -1040
.
.                                                      60 lines      Inner perimeter
.
create vertex  -985.54        -98.50         -1040
create vertex  -982.57        -88.52         -1040
create vertex  -980.36        -78.28         -1040
### Drawdown 1 ----------------------------------                                       Top
create vertex  -965.58        -68.16         -1040
create vertex  -960.01        -55.54         -1040
create vertex  -964.22        -43.53         -1040
.
.                                                                    Outer perimeter
.
create vertex  -975.13        -88.08         -1060
create vertex  -972.87        -77.25         -1060
create vertex  -971.66        -66.32         -1060
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -965.98        -55.38         -1060
create vertex  -961.64        -43.38         -1060
create vertex  -963.72        -31.56         -1060
.
.                                                                    Inner perimeter
.
create vertex  -975.13        -88.08         -1060
create vertex  -972.87        -77.25         -1060
create vertex  -971.66        -66.32         -1060
### Drawdown 1 ----------------------------------                                       Bottom
create vertex  -958.15        -55.62         -1060
create vertex  -953.50        -42.76         -1060
create vertex  -955.73        -30.08         -1060
.
.                                                                    Outer perimeter
.
create vertex  -967.96        -90.69         -1060
create vertex  -965.55        -79.08         -1060
create vertex  -964.25        -67.36         -1060
```

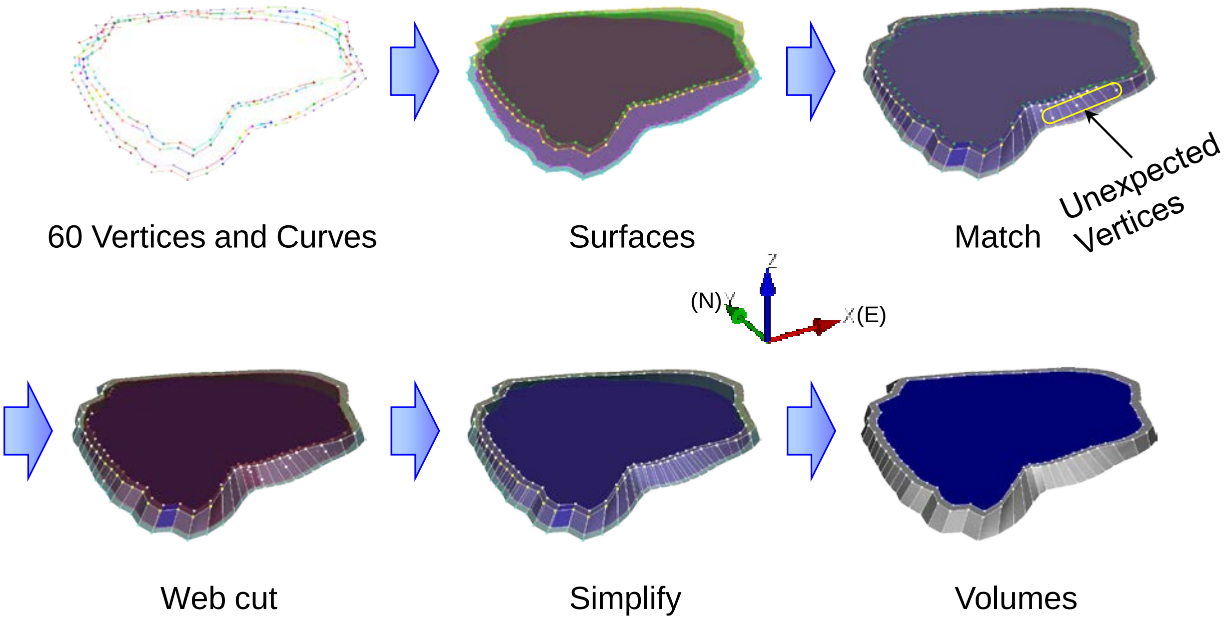


Figure 27: Steps to create BC-1 cavern slice volume whose bottom elevation is -1060 ft

File 23: mesh_wall.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
#### Smoothing ------------------------
surface in sdl0b smooth scheme cond
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Sideset ==================================================
sideset {BID+VI0} surface in sdl0w wrt volume {VDL1}
```

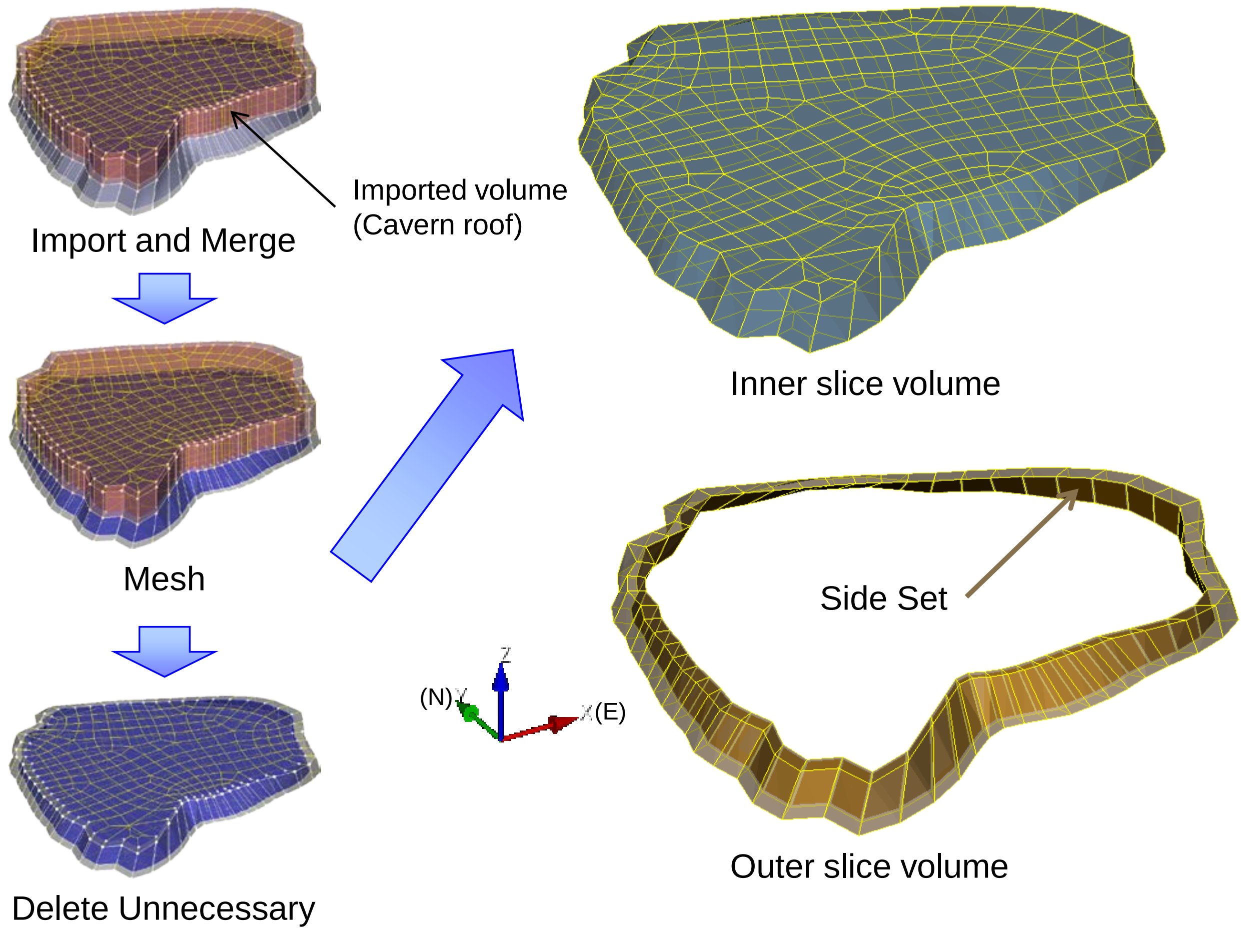


Figure 28: Steps to mesh BC-1 cavern slice volume whose bottom elevation is -1060 ft

6.1.8. Floor block

The Cubit journal file **`bot_1840_floor.jou`** (File 8) creates the cavern floor block. File 24 shows the Cubit journal file to create the vertices for the BC-1 floor block. The elevations of the top and bottom of the roof block are -1820 ft and -1840 ft, respectively. The cavern floor volumes are created using **`create_vol.jou`** (File 11) as shown Figure 29.

To create the mesh in the volumes, **`mesh_floor.jou`** (File 25) is used. Figure 30 shows the steps to create the mesh into the cavern floor block. As the first step, the cavern slice block over the floor block is imported, and the bottom surfaces of the cavern slice block and the top surfaces of the floor block are merged to transfer the mesh. As the next step, the vertical curves on the floor block are meshed with one interval because the thickness of the floor block is 20 ft, and then the volumes in the floor block are meshed fully. As the third step, the imported cavern slice block is deleted. As the last step, the side set is defined on the top of the floor block as `Sideset 11840` to represent the cavern floor.

The meshed inner and outer volumes are defined as `Element Block 11840` and `Element Block 11841`, respectively. The meshed upper salt block is saved through the command scripts in **`save.jou`** (File 21).

File 24: vtx_1840.jou

```
# Top elevation       : {TELE=       -1820   }ft
# Bottom elevation    : {BELE=       -1840   }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -998.76        -17.79         -1820
create vertex  -997.84        -9.83          -1820
create vertex  -997.88        -1.70          -1820
.
.                                                     60 lines      Inner perimeter
.
create vertex  -1006.21       -39.68         -1820
create vertex  -1002.31       -32.94         -1820
create vertex  -999.64        -25.56         -1820
### Drawdown 1 ----------------------------------                                    Top
create vertex  -993.39        -17.69         -1820
create vertex  -992.40        -9.15          -1820
create vertex  -992.44        -0.43          -1820
.
.                                                                   Outer perimeter
.
create vertex  -1001.37       -41.16         -1820
create vertex  -997.20        -33.93         -1820
create vertex  -994.33        -26.02         -1820
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -998.76        -17.79         -1840
create vertex  -997.84        -9.83          -1840
create vertex  -997.88        -1.70          -1840
.
.                                                                   Inner perimeter
.
create vertex  -1006.21       -39.68         -1840
create vertex  -1002.31       -32.94         -1840
create vertex  -999.64        -25.56         -1840
### Drawdown 1 ----------------------------------                                    Bottom
create vertex  -993.39        -17.69         -1840
create vertex  -992.40        -9.15          -1840
create vertex  -992.44        -0.43          -1840
.
.                                                                   Outer perimeter
.
create vertex  -1001.37       -41.16         -1840
create vertex  -997.20        -33.93         -1840
create vertex  -994.33        -26.02         -1840
```

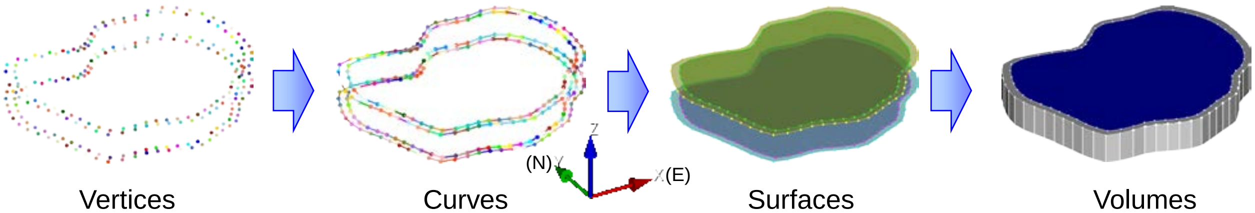


Figure 29: Vertices, curves, surfaces, and volumes at floor of BC-1

File 25: mesh_floor.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Sideset ====================================================
sideset {BID+VI0} surface in sdl0t wrt volume {VDL0}
```

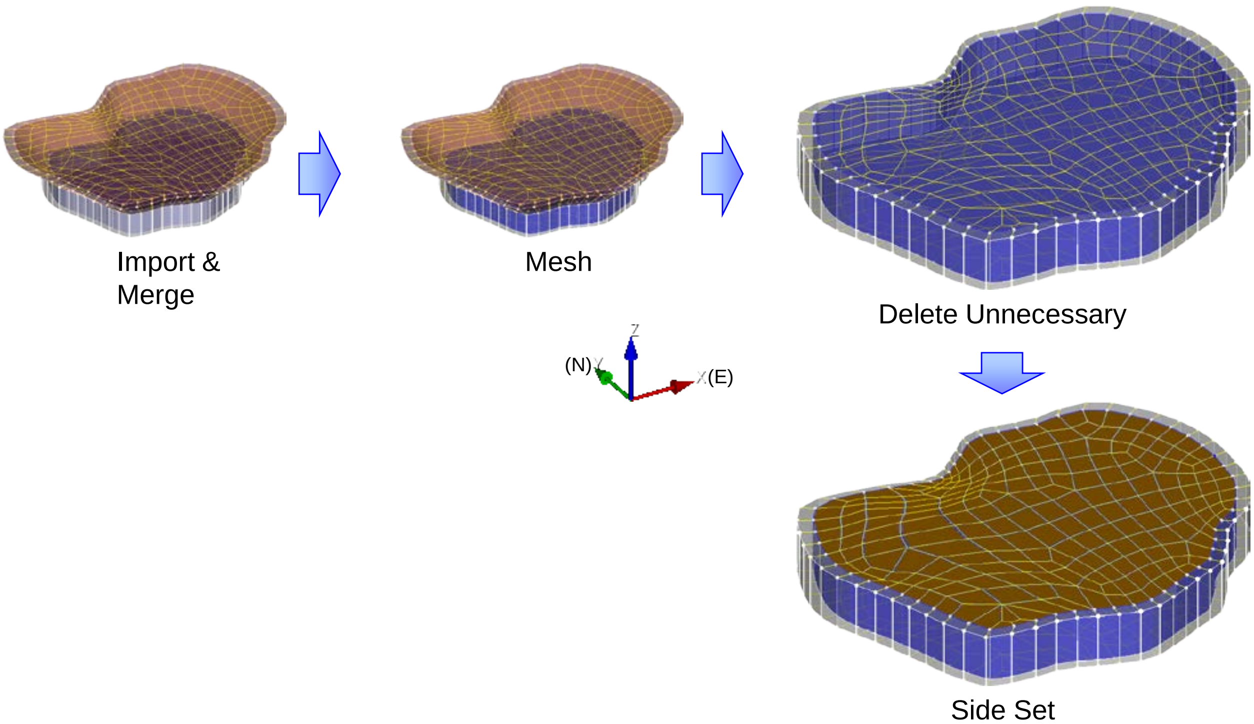


Figure 30: Steps to mesh BC-1 cavern floor whose bottom elevation is -1840 ft

6.1.9. Lower salt block

The Cubit journal file **`bot_6400_below.jou`** (File 9) creates the lower salt block under the cavern. **`vtx_6400.jou`** (File 24) is the Cubit journal file to create the vertices for the BC-1 lower salt block. The elevations of the top and bottom of the lower salt block are -1840 ft and -6400 ft, respectively. The volumes in the lower salt block are created using **`create_vol.jou`** (File 11) as shown Figure 29.

To create the mesh in the volumes, **`mesh_below_wo_ss.jou`** (File 27) is used. Figure 32 shows the steps to create the mesh into the lower salt block. As the first step, the cavern floor block is imported over the lower salt block, and the bottom surfaces of the floor block and the top surfaces of the lower salt block are merged to transfer the mesh. As the next step, the vertical curves on the lower salt block are meshed with 228 intervals because the height of the lower salt block is 4560 ft, and then the volumes in the lower salt block are meshed fully. As the third step, the imported floor block is deleted. As the last step, the node set on the bottom of the lower salt block is defined as `Nodeset 10003` which will be added on the bottom node set of the entire model.

The meshed inner and outer volumes are defined as `Element Blocks 16400` and `16401`, respectively. The meshed lower salt block is saved through the command scripts in **`save_wo_ss.jou`** (File 28).

File 26: vtx_6400.jou

```
# Top elevation       : {TELE=       -1840   }ft
# Bottom elevation     : {BELE=       -6400   }ft
# Cavern ID    : {CID=001*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -998.76        -17.79         -1840
create vertex  -997.84        -9.83          -1840
create vertex  -997.88        -1.70          -1840
.
.
.
create vertex  -1006.21       -39.68         -1840
create vertex  -1002.31       -32.94         -1840
create vertex  -999.64        -25.56         -1840
### Drawdown 1 ----------------------------------
create vertex  -993.39        -17.69         -1840
create vertex  -992.40        -9.15          -1840
create vertex  -992.44        -0.43          -1840
.
.
.
create vertex  -1001.37       -41.16         -1840
create vertex  -997.20        -33.93         -1840
create vertex  -994.33        -26.02         -1840
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -998.76        -17.79         -6400
create vertex  -997.84        -9.83          -6400
create vertex  -997.88        -1.70          -6400
.
.
.
create vertex  -1006.21       -39.68         -6400
create vertex  -1002.31       -32.94         -6400
create vertex  -999.64        -25.56         -6400
### Drawdown 1 ----------------------------------
create vertex  -993.39        -17.69         -6400
create vertex  -992.40        -9.15          -6400
create vertex  -992.44        -0.43          -6400
.
.
.
create vertex  -1001.37       -41.16         -6400
create vertex  -997.20        -33.93         -6400
create vertex  -994.33        -26.02         -6400
```

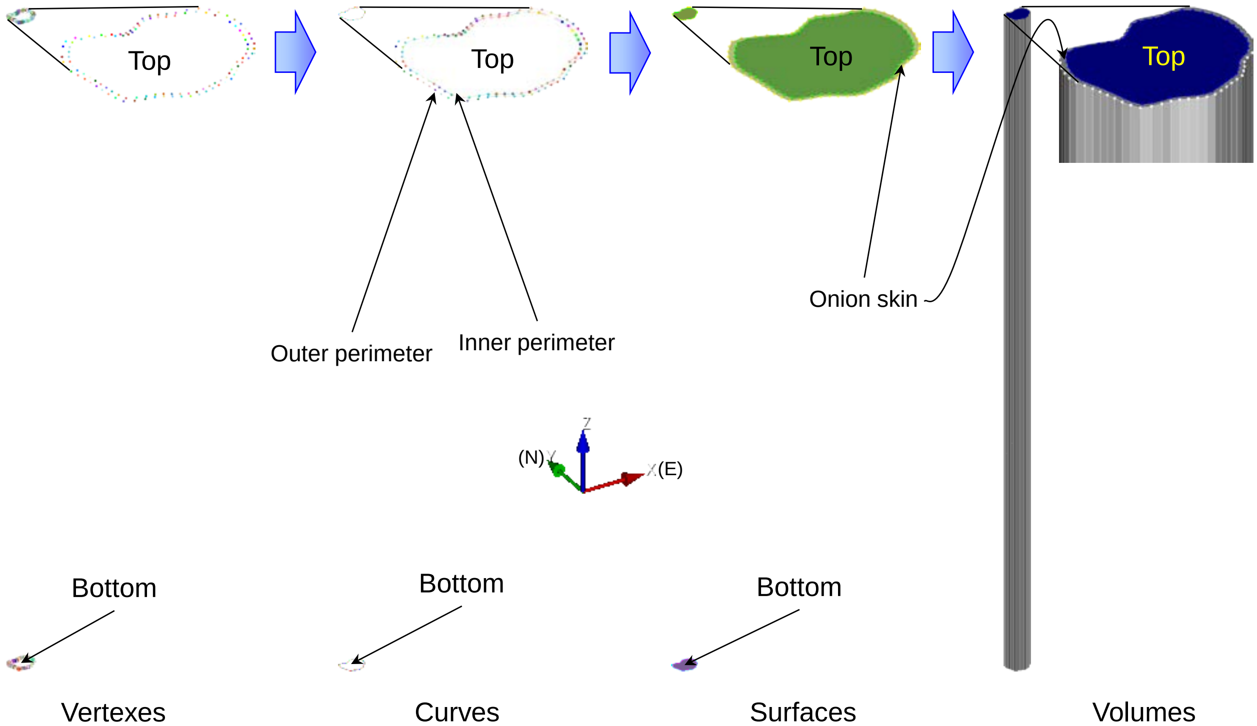


Figure 31: Vertices, curves, surfaces, and volumes for lower salt block of BC-1

File 27: mesh_below_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ---------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Node Set ====================================================
nodeset {CID+3} surface in bsurf
```

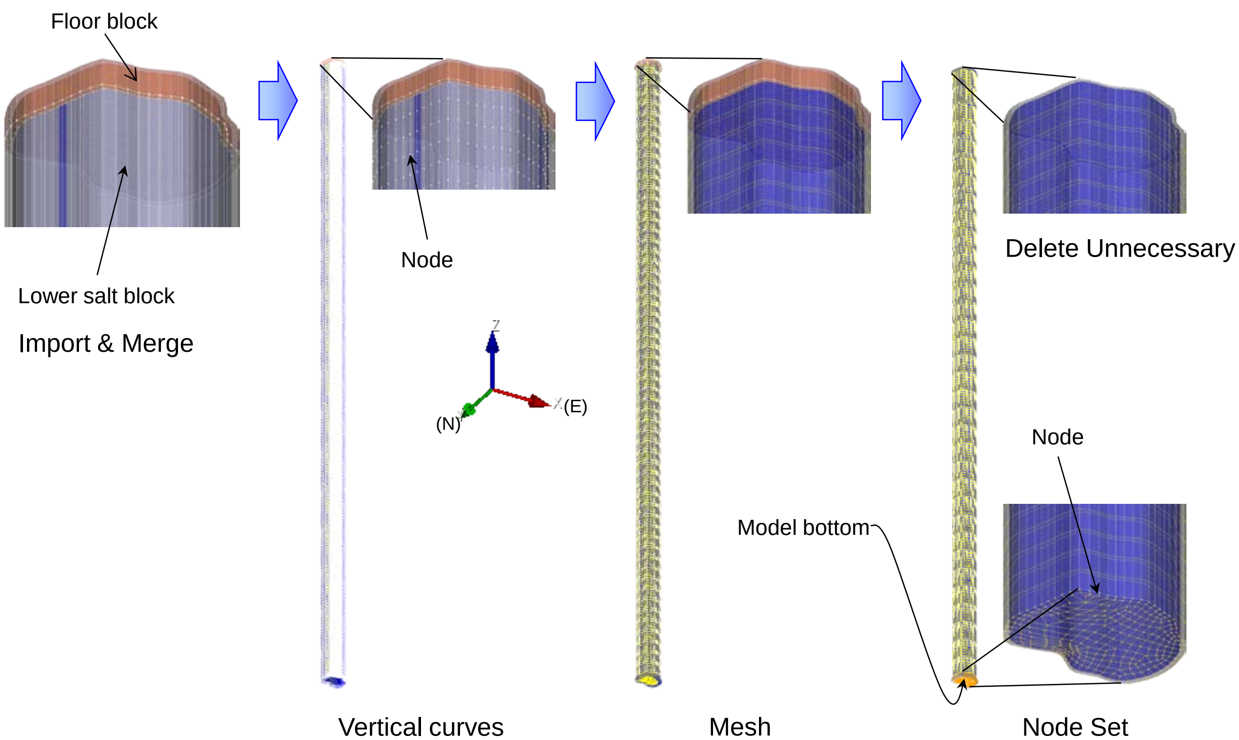


Figure 32: Steps to mesh BC-1 lower salt block whose bottom elevation is -6400 ft

File 28: save_wo_ss.jou

```
# Save ==============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_"//tostring(-
BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\g0\bc001_"//tostring(-
BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\abs\bc001_abstract.txt")}
resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-BELE)//".cub")}
overwrite
set logging off
echo on
delete volume all except {skn}
delete block all
delete nodeset all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-
BELE)//"_skn.cub")} overwrite
```

6.1.10. Cavern column

46 meshed blocks created in Section 6.1.3 through 6.1.9 are assembled into the BC-1 cavern column as shown Figure 33 through the GJOIN process on Redsky[5]. **bc001.gjn** (File 29) shows

5 Redsky is a platform which provides computing resources in the Sandia networks.

the GJOIN scripts. The Genesis file of BC-1 cavern column is saved as **bc001.g1** into the directory of /fscratch/bypark/BC_sonar/mesh/bc001g1/. **bc001.g1** will be assembled into the entire model mesh of **bc_20ft.g0**.

The ID digits used hereafter were described in Section 3.5. As the first step, two Genesis files **bc_001_500.g0** and **bc_001_660.g0** are combined with the tolerance of 1.E-02. The inner cavern slice volume in the overburden layer (Element Block 10500, GJOIN ID is 1) is assigned to the overburden block in the entire model as Element Block 2001. The outer cavern skin slice volume in the overburden layer (Element Block 10501) is combined to Element Block 2001. The inner cavern slice volume in the caprock layer (Element Block 10660, GJOIN ID is 3) is assigned to the caprock block in the entire model as Element Block 3001. The outer cavern skin slice volume in the caprock layer (Element Block 10661) is combined to Element Block 3001.

As the second step, the Genesis file **bc001_680.g0** is combined to the combined two Genesis files above. The inner cavern slice volume in the interbed layer (Element Block 10680, GJOIN ID is 3) is assigned to the interbed block in the entire model as Element Block 8001. The outer cavern skin slice volume in the interbed layer (Element Block 10681) is combined to Element Block 8001.

As the third step, the Genesis file **bc001_1020.g0** is combined to the combined three Genesis files above. The inner cavern slice volume in the upper salt layer (Element Block 11020, GJOIN ID is 4) is assigned to the salt block in the entire model as Element Block 1001. The outer cavern skin slice volume in the upper salt layer (Element Block 11021) is combined to Element Block 1001.

As the fourth step, the Genesis file **bc001_1040.g0** is combined to the combined four Genesis files above. The inner cavern slice volume in the roof layer (Element Block 11040, GJOIN ID is 5) is assigned to the salt block in the entire model as Element Block 10011. The cavern roof is regarded as cavern onion skin. The outer cavern skin slice volume in the roof layer (Element Block 11041) is combined to Element Block 10011. The side set on the bottom of the inner cavern slice volume (Sideset 11040, GJOIN ID 1) is assigned to the side set in the entire model as Sideset 10 which represents the ceiling of the cavern.

As the fifth step, the Genesis file **bc001_1060.g0** is combined to the combined five Genesis files above. The inner cavern slice volume in the cavern layer (Element Block 11060, GJOIN ID is 6) is assigned to the salt block in the entire model as Element Block 10010. The outer cavern skin slice volume in the cavern layer (Element Block 11061) is combined to Element Block 10011. The side set on the inside of the outer cavern skin slice volume (Sideset 11060) is assigned to the side set in the entire model as Sideset 10 which represents the wall of the cavern. Therefore, Sideset 10 represents the inside surface of the cavern because the side sets for the ceiling above, the wall, and the floor below are combined into Sideset 10 together.

As the sixth step, the Genesis file **bc001_1080.g0** is combined to the combined six Genesis files above. The inner cavern slice volume in the cavern layer (Element Block 11080) is assigned to the salt block in the entire model as Element Block 10010. The outer cavern skin slice volume in the cavern layer (Element Block 11081) is combined to Element Block 10011. The side set on the inside of the outer cavern skin slice volume (Sideset 11080) is assigned to the side set in the entire model as Sideset 10.

As same manner as the sixth step, the geneses files through **bc001_1820.g0** are combined to the combined Genesis files right above **bc001_1820.g0**.

As the next step, the Genesis file **`bc001_1840.g0`** is combined to the combined 44 Genesis files above (BC-1 cavern column consists of 46 cavern slice blocks). The inner cavern slice volume in the floor layer (`Element Block 11840`) is assigned to the salt block in the entire model as `Element Block 10011`. The cavern floor is regarded as cavern onion skin. The outer cavern skin slice volume in the floor layer (`Element Block 11841`) is combined to `Element Block 10011`. The side set on the top of the inner cavern slice volume (`Sideset 11840`) is assigned to the side set in the entire model as `Sideset 10` which represents the floor of the cavern.

As the last step, the Genesis file **`bc001_6400.g0`** is combined to the combined 45 Genesis files above. The inner cavern slice volume in the lower salt layer (`Element Block 16400`) is assigned to the salt block in the entire model as `Element Block 1001`. The outer cavern skin slice volume in the lower salt layer (`Element Block 16401`) is combined to `Element Block 1001`. The node set on the bottom of the lower salt block (`Nodeset 10003, GJOIN ID 1`) is redefined as `Nodeset 3001` which represents the bottom boundary of BC-1 cavern column.

File 29: bc001.gjn

```
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_500.g0
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_660.g0
comb
1.00E-02
no
blocks
id 1 2001
id 3 3001
combine 2001 10501
combine 3001 10661
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_680.g0
comb
1.00E-02
no
blocks
id 3 8001
combine 8001 10681
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1020.g0
comb
1.00E-02
no
blocks
id 4 1001
combine 1001 11021
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1040.g0
comb
1.00E-02
no
blocks
id 5 10011
combine 10011 11041
up
sset
id 1 10
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1060.g0
comb
1.00E-02
no
blocks
id 6 10010
combine 10011 11061
up
sset
combine 10 11060
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1080.g0
comb
1.00E-02
no
blocks
combine 10010 11080
combine 10011 11081
up
sset
combine 10 11080
up

(To be continued)
```

```
.
.
.

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1820.g0
comb
1.00E-02
no
blocks
combine 10010 11820
combine 10011 11821
up
sset
combine 10 11820
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_1840.g0
comb
1.00E-02
no
blocks
combine 10011 11840
combine 10011 11841
up
sset
combine 10 11840
up

add
/fscratch/bypark/BC_sonar/mesh/bc001/bc001_6400.g0
comb
1.00E-02
no
blocks
combine 1001 16400
combine 1001 16401
up
nset
id 1 3001
up

finish
/fscratch/bypark/BC_sonar/mesh/bc001g1/bc001.g1
```

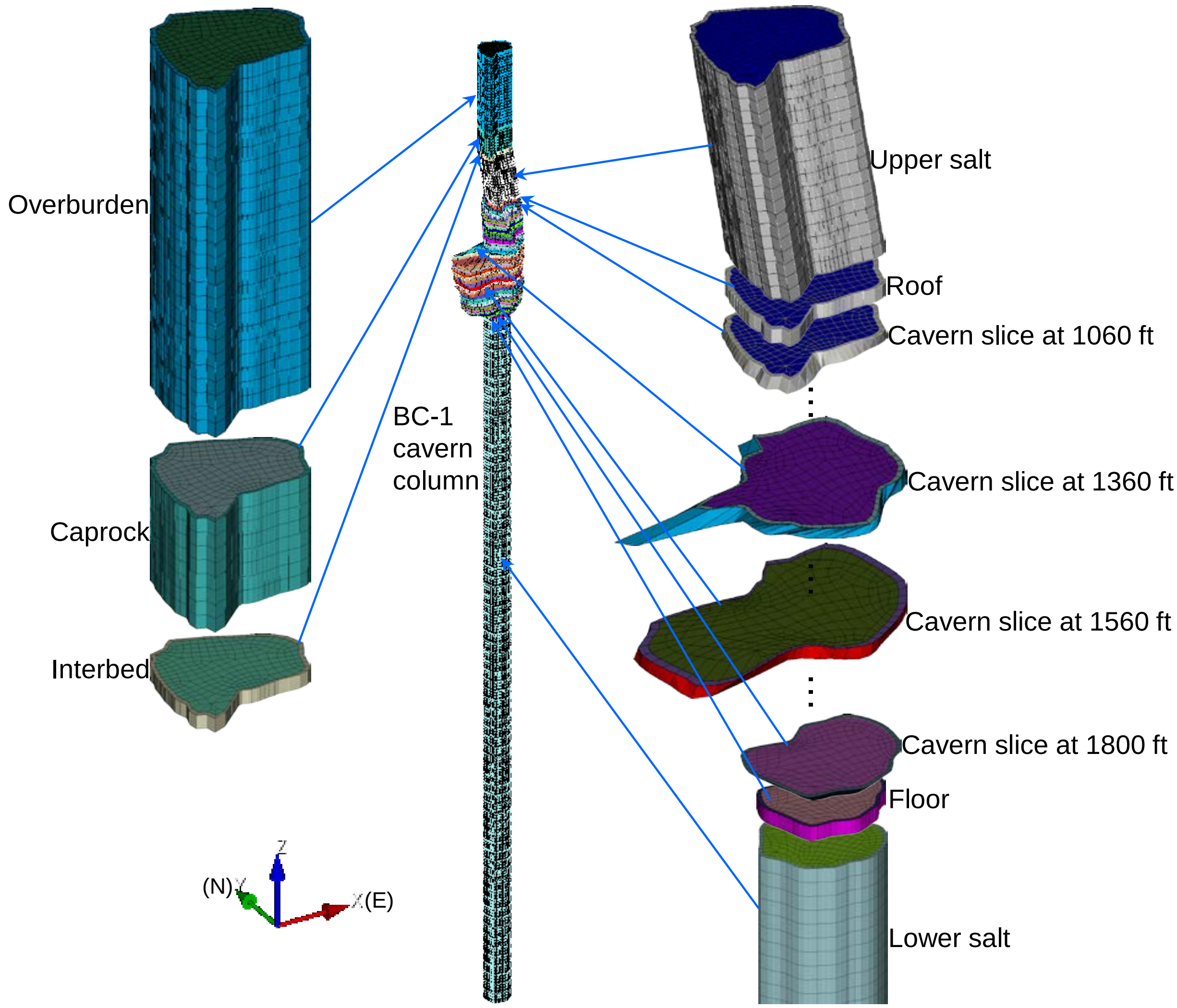


Figure 33: BC-1 cavern column

6.2. BC-4

BC-4 is an abnormal shape cavern in the non-SPR caverns. The cavern is leached through three lithological layers, i.e. the caprock, interbed and salt layers. BC-4 stability has been the object of continuing concern because of its geologic similarity to collapsed BC-7 (now Cavern Lake). Sonar results in 1992 show minimal change since 1980, suggesting that significant caprock dissolution has not occurred and that overburden collapse is unlikely. However, continuing surveillance is prudent [Neal et al., 1993].

6.2.1. Data conversion

Figure 34 shows the sonar image and resampled nodes for BC-4. Each node has X-, Y-, Z-coordinates. The node coordinate data are converted into the vertices data with the Cubit input format through MS Excel manipulation as mentioned for BC-1 (Section 6.1.1).

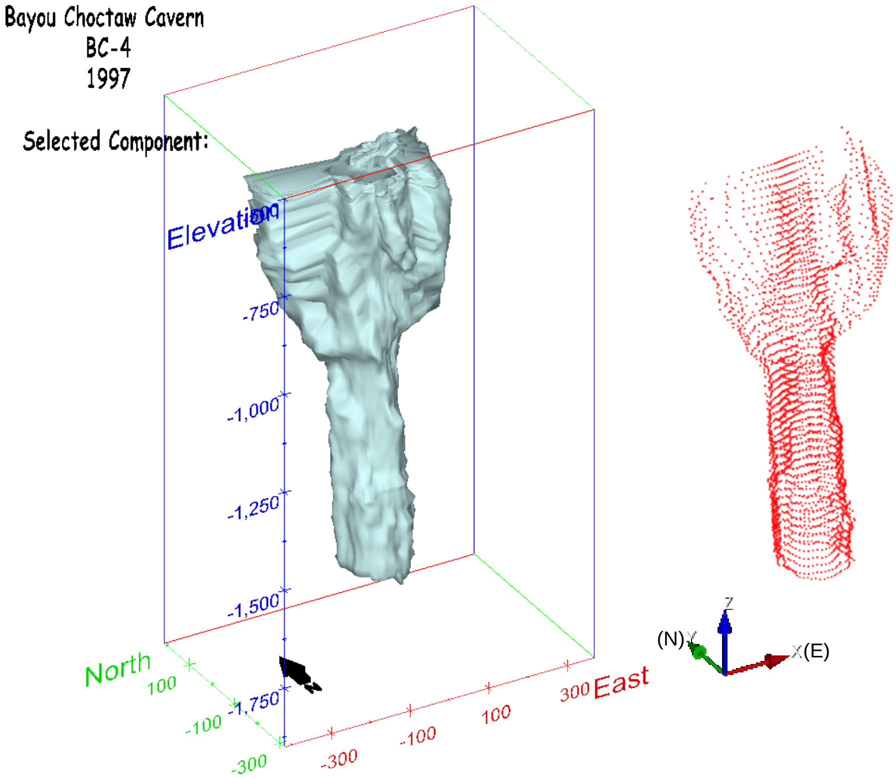


Figure 34: Sonar image (left) and resampled nodes from the sonar image for BC-1

6.2.2. Cubit batch files

File 30 shows the Cubit batch run script for BC-4. These command scripts are executed on the Command Prompt Window as shown Figure 17. As the first step, the sub-Cubit journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_sub\`. As the next step, the vertex journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_vtx\`. As the third step, the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou` and then Cubit batch commands are executed. After a series of Cubit batch journal files (File 30) execute completely, meshed 54 cavern slice blocks are created.

As listed in Table 2, **`bot_0500_surface.jou`** creates the meshed block in the overburden layer. In the file name of **`bot_0640_roof.jou`** (File 31), **`bot_0640`** indicates the bottom elevation of the block is -640 ft which is the elevation of the cavern ceiling. **`_roof`** indicates the cavern roof block. In the file name of **`bot_0660.jou`** (File 32), **`bot_0660`** indicates the bottom elevation of the block is -660 ft. In the file name of **`bot_1680_floor.jou`** (File 33), **`bot_1680`** indicates the bottom elevation of the block is -1680 ft which minus 20 ft, i.e. -1660 ft is the elevation of the cavern floor. In the file name of **`bot_2700_below.jou`** (File 34), **`bot_2700`** indicates the bottom elevation of the block is -2700 ft which is the elevation of the moderate block bottom as a lower salt block. **`_below`** indicates the block is created below the cavern. In the file name of **`bot_6400_bottom.jou`** (File 35), **`bot_6400`** indicates the bottom elevation of the block is -6400 ft which is the elevation of the model bottom as a lower salt block. **`_bottom`** indicates the block is created for the model bottom.

File 30: Cubit batch run script for BC-4

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho bot_0500_surface.jou
Cubit –batch –nographics –noecho bot_0640_roof.jou
Cubit –batch –nographics –noecho bot_0660.jou
Cubit –batch –nographics –noecho bot_0680.jou
Cubit –batch –nographics –noecho bot_0700.jou
Cubit –batch –nographics –noecho bot_0720.jou
Cubit –batch –nographics –noecho bot_0740.jou
Cubit –batch –nographics –noecho bot_0760.jou
Cubit –batch –nographics –noecho bot_0780.jou
Cubit –batch –nographics –noecho bot_0800.jou
Cubit –batch –nographics –noecho bot_0820.jou
Cubit –batch –nographics –noecho bot_0840.jou
Cubit –batch –nographics –noecho bot_0860.jou
Cubit –batch –nographics –noecho bot_0880.jou
Cubit –batch –nographics –noecho bot_0900.jou
Cubit –batch –nographics –noecho bot_0920.jou
Cubit –batch –nographics –noecho bot_0940.jou
Cubit –batch –nographics –noecho bot_0960.jou
Cubit –batch –nographics –noecho bot_0980.jou
Cubit –batch –nographics –noecho bot_1000.jou
Cubit –batch –nographics –noecho bot_1020.jou
Cubit –batch –nographics –noecho bot_1040.jou
Cubit –batch –nographics –noecho bot_1060.jou
Cubit –batch –nographics –noecho bot_1080.jou
Cubit –batch –nographics –noecho bot_1100.jou
Cubit –batch –nographics –noecho bot_1120.jou
Cubit –batch –nographics –noecho bot_1140.jou
Cubit –batch –nographics –noecho bot_1160.jou
Cubit –batch –nographics –noecho bot_1180.jou
Cubit –batch –nographics –noecho bot_1200.jou
Cubit –batch –nographics –noecho bot_1220.jou
Cubit –batch –nographics –noecho bot_1240.jou
Cubit –batch –nographics –noecho bot_1260.jou
Cubit –batch –nographics –noecho bot_1280.jou
Cubit –batch –nographics –noecho bot_1300.jou
Cubit –batch –nographics –noecho bot_1320.jou
Cubit –batch –nographics –noecho bot_1340.jou
Cubit –batch –nographics –noecho bot_1360.jou
Cubit –batch –nographics –noecho bot_1380.jou
Cubit –batch –nographics –noecho bot_1400.jou
Cubit –batch –nographics –noecho bot_1420.jou
Cubit –batch –nographics –noecho bot_1440.jou
Cubit –batch –nographics –noecho bot_1460.jou
Cubit –batch –nographics –noecho bot_1480.jou
Cubit –batch –nographics –noecho bot_1500.jou
Cubit –batch –nographics –noecho bot_1520.jou
Cubit –batch –nographics –noecho bot_1540.jou
Cubit –batch –nographics –noecho bot_1560.jou
Cubit –batch –nographics –noecho bot_1580.jou
Cubit –batch –nographics –noecho bot_1600.jou
Cubit –batch –nographics –noecho bot_1620.jou
Cubit –batch –nographics –noecho bot_1640.jou
Cubit –batch –nographics –noecho bot_1660.jou
Cubit –batch –nographics –noecho bot_1680_floor.jou
Cubit –batch –nographics –noecho bot_2700_below.jou
Cubit –batch –nographics –noecho bot_6400_bottom.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\vtx\
```

File 31: bot_0640_roof.jou

```
# Graphic Window Size ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_0640.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_roof.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 32: bot_0660.jou

```
# Setup environment  ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_0660.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 33: bot_1680_floor.jou

```
# Setup environment  ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_1680.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_floor.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 34: bot_2700_below.jou

```
# Setup environment  ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2700.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_below_wo_ss.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ss.jou")}
#
exit
```

File 35: bot_6400_bottom.jou

```
# Setup environment  ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6400.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_bottom_wo_ss.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ss.jou")}
#
exit
```

6.2.3. Block in overburden layer

File 36 shows the Cubit input journal file to create the vertices for the BC-4 cavern slice block in the overburden layer. The elevations of the top and bottom of the block are zero ft and -500 ft, respectively. BC-4 consists of 60 vertices on a perimeter of the cavern wall. As mentioned in Section 3.1, BC-4 considers one onion skin as shown in Figure 35. The coordinate values of the outer perimeter vertices (`Drawdown 1`) in File 36 are calculated using Eq. (4).

`create_vol.jou` (File 11) is used to create the cavern column block in the overburden layer like BC-1. The difference only is that the error messages will be recorded into **`bc004_0500.err`** and **`bc004_0500.log`** in the following directory:

```
C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\err\
C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\log\
```

To generate the mesh into the volumes, the Cubit command scripts in File 37 (similar to File 12 for BC-1) are used. Figure 36 through Figure 38 show the steps to create mesh into the volume. To keep the key methodologies as mentioned in Section 6.1.3.2, the top surface of the inner volume (`Drawdown 0`) is meshed using the following scripts:

```
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
```

Figure 36 (top left) shows the mesh on the top of the inner volume after executing the scripts above. In spite of applying option `type side`, mesh lines are not created at Vertices P and Q. To create a mesh line at P and Q each, the following scripts are used:

```
volume all move {vamx=288.12973} {vamy= 72.975865}
pillow face in surface in sdl0t
volume all move {-vamx} {-vamy}
```

To prevent the Cubit algorithm from becoming unstable, move the coordinates of the surface center to (0, 0) using `volume all move {vamx=288.12973} {vamy= 72.975865}` first, because the center coordinates of the surface is (-288.12973, -72.975865). `pillow face` creates mesh lines at P and Q (bottom right in Figure 36). After that, return the volume to the original location using `volume all move {-vamx} {-vamy}`.

Figure 37 (bottom right) shows the mesh on the top of the inner volume after `smooth surface`. To improve the mesh quality, “smoothing” steps are conducted until no smoothing is needed with the following scripts:

```
#### Smoothing ------------------------
surface in sdl0t smooth scheme cond
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
```

After the “smoothing” steps, the mesh quality at the element having the minimum quality is improved from 2.422e-01 to 2.758e-01.

The top surface of the outside volume (Drawdown 1) is meshed as shown Figure 38 through the following scripts:

```
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1
mesh surface in sdl1t
```

To prevent creating skewed mesh, `scheme hole rad_intervals 1` is applied.

The vertical curves on the volume are divided by 20 ft then 25 element levels are created because the thickness of the overburden layer is 500 ft. Then, the volumes are meshed entirely with the meshed horizontal sections and vertical curves.

The meshed block is saved to storage through **`save_wo_ns_ss.jou`** (File 14) (replacing 001 with 004). The Cubit output (**`bc004_500.cub`**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\cub\`, and the Genesis file (**`bc004_500.g0`**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\g0\`. The abstract file (**`bc004_500.abs`**) shows the mesh information such as the mesh quality; and numbers of side sets, node sets, elements, and nodes, etc. The abstract file will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\abs\`. The onion skin volume (**`bc004_500_skn.cub`**) will be saved into the same directory for the Cubit output.

File 36: vtx_0500.jou

```
# Top elevation        : {TELE=       0      }ft
# Bottom elevation     : {BELE=       -500    }ft
# Cavern ID    : {CID=004*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         0
create vertex  -129.78        -49.41         0
create vertex  -123.42        -30.54         0
.
.
.
create vertex  -118.61        -119.18        0
create vertex  -120.41        -100.51        0
create vertex  -128.02        -82.52         0
### Drawdown 1 -----------------------------------
create vertex  -122.74        -65.34         0
create vertex  -118.83        -47.34         0
create vertex  -112.01        -27.11         0
.
.
.
create vertex  -106.85        -122.16        0
create vertex  -108.78        -102.13        0
create vertex  -116.94        -82.84         0
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         -500
create vertex  -129.78        -49.41         -500
create vertex  -123.42        -30.54         -500
.
.
.
create vertex  -118.61        -119.18        -500
create vertex  -120.41        -100.51        -500
create vertex  -128.02        -82.52         -500
### Drawdown 1 -----------------------------------
create vertex  -122.74        -65.34         -500
create vertex  -118.83        -47.34         -500
create vertex  -112.01        -27.11         -500
.
.
.
create vertex  -106.85        -122.16        -500
create vertex  -108.78        -102.13        -500
create vertex  -116.94        -82.84         -500
```

60 lines

Inner perimeter

Top

Outer perimeter

Inner perimeter

Bottom

Outer perimeter

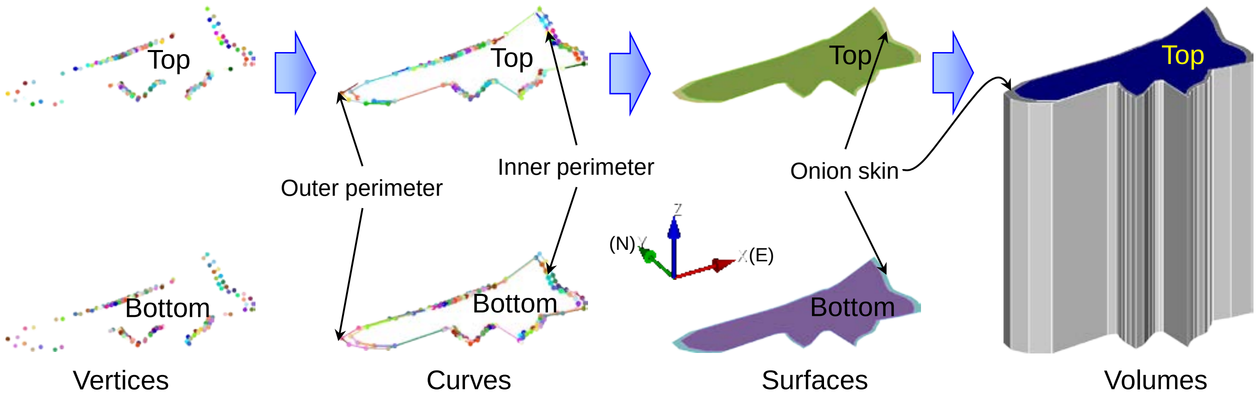


Figure 35: Vertices, curves, surfaces, and volumes of BC-1 column in overburden layer

File 37: mesh_surface.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
#### fix no mesh line at vertices
#### quality surface in sdl0t ******!! Use this when needed only
#### To fine  Overall Centroid: "list volume all geom"
### Overall Centroid: X = -288.12973
###                   Y = -72.975865
volume all move {vamx=288.12973} {vamy= 72.975865}
pillow face in surface in sdl0t
volume all move {-vamx} {-vamy}
#### Smoothing ------------------------
surface in sdl0t smooth scheme cond
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
### Drawdown 1 ----------------------------------
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl1t
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
# Define Blocks ==================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
```

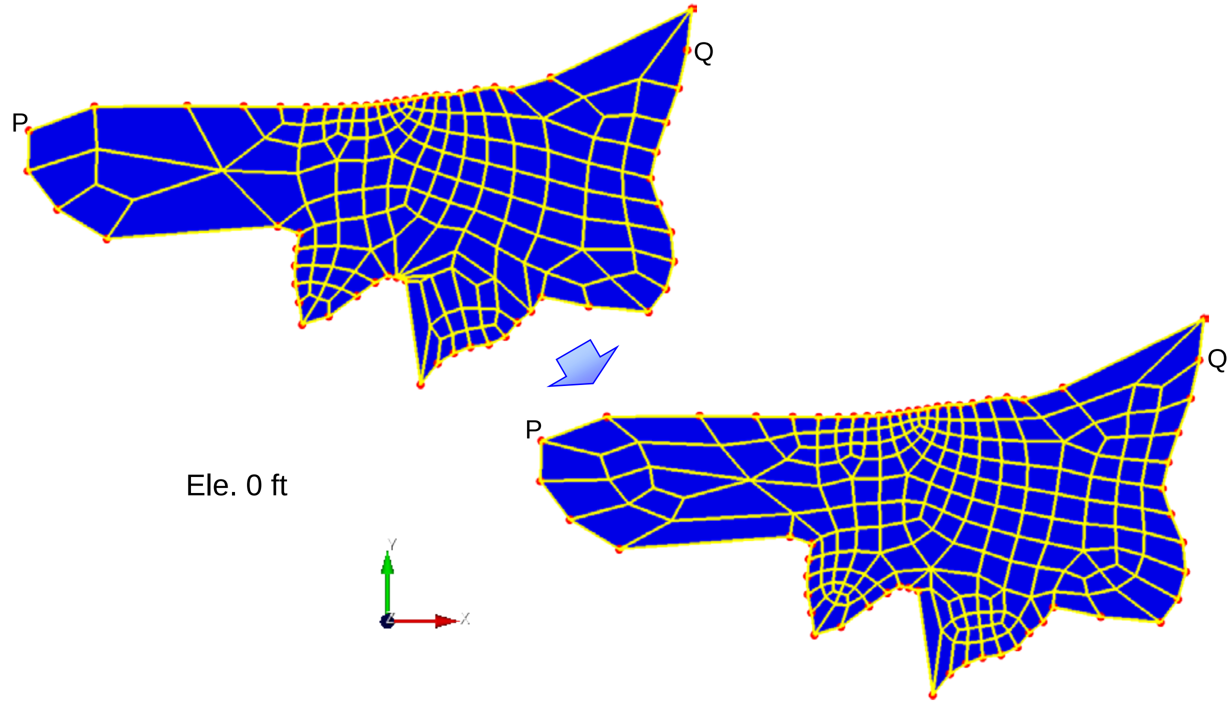


Figure 36: Pillow face in surface

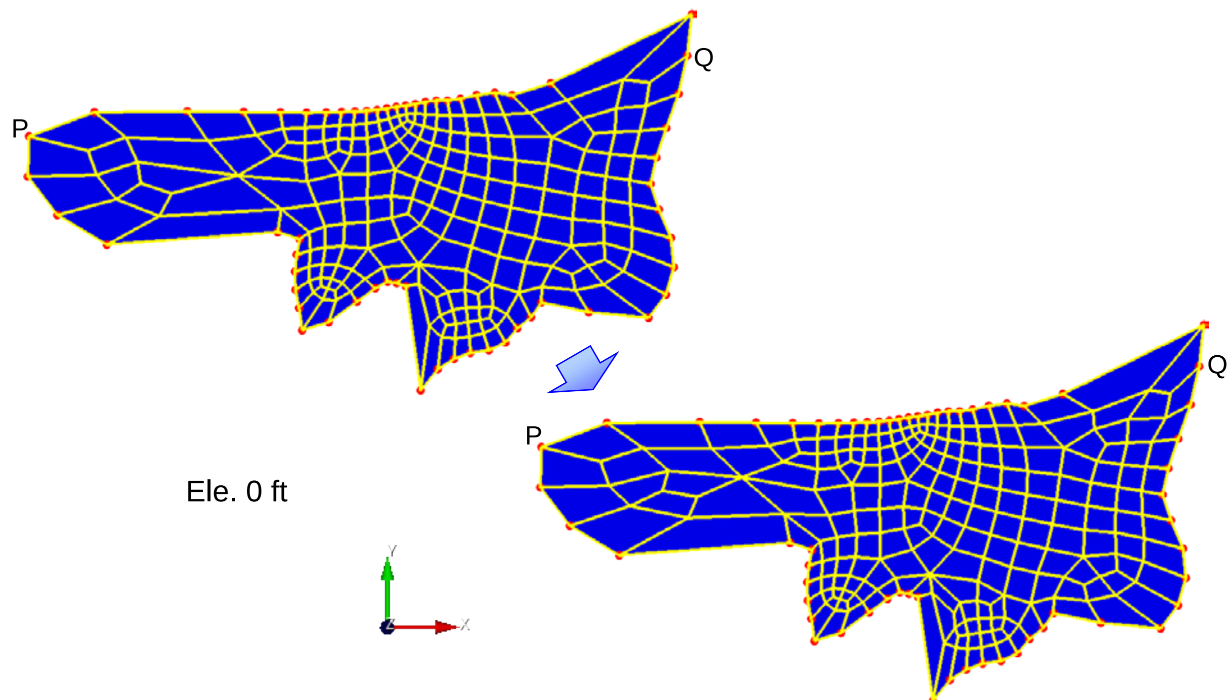


Figure 37: Smooth surface

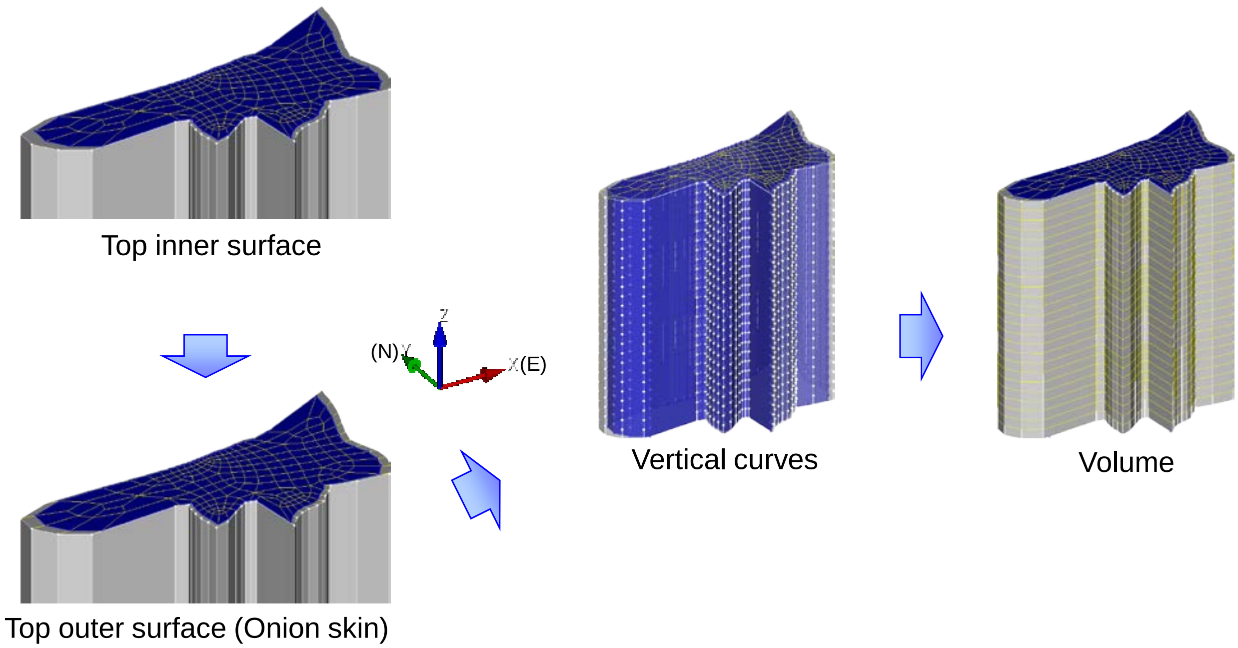


Figure 38: Steps to create mesh into BC-4 cavern column in overburden layer

6.2.4. Roof block in caprock

The Cubit journal file **`bot_0640_roof.jou`** (File 31) creates the volumes for the cavern roof. **`vtx_0640.jou`** (File 38) is the Cubit journal file to create the vertices for the BC-4 cavern roof block. The elevations of the top and bottom of the roof block are -500 ft and -640 ft, respectively. The cavern roof volumes are created using **`create_vol.jou`** (File 11) (replacing 001 with 004) as shown Figure 39.

To create the mesh in the volumes, **`mesh_roof.jou`** (File 20) (replacing 001 with 004) is used. Figure 40 shows the steps to create the mesh into the cavern roof in the caprock layer. As the first step, the block in the overburden layer is imported right above the cavern roof block, and the bottom surfaces of the overburden block and the top surfaces of the roof block are merged to transfer the mesh. As the next step, the vertical curves on the roof block are meshed with seven intervals because the thickness of the roof block is 140 ft, and then the volumes in the roof block are meshed entirely. As the third step, the imported upper salt block is deleted. As the last step, the side set is defined as `Sideset 40640` to represent the ceiling of the cavern on the bottom of the roof block.

The meshed inner and outer volumes are defined as `Element Block 40640` and `Element Block 40641`, respectively. The meshed upper salt block is saved through the command scripts in **`save.jou`** (File 21) used for the overburden layer (replacing 001 by 004).

File 38: vtx_0640.jou

```
# Top elevation       : {TELE=      -500    }ft
# Bottom elevation    : {BELE=      -640    }ft
# Cavern ID    : {CID=004*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer    : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         -500
create vertex  -129.78        -49.41         -500
create vertex  -123.42        -30.54         -500
.
.                                                   60 lines    Inner perimeter
.
create vertex  -118.61        -119.18        -500
create vertex  -120.41        -100.51        -500
create vertex  -128.02        -82.52         -500
### Drawdown 1 ----------------------------------                            Top
create vertex  -122.74        -65.34         -500
create vertex  -118.83        -47.34         -500
create vertex  -112.01        -27.11         -500
.
.                                                               Outer perimeter
.
create vertex  -106.85        -122.16        -500
create vertex  -108.78        -102.13        -500
create vertex  -116.94        -82.84         -500
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         -640
create vertex  -129.78        -49.41         -640
create vertex  -123.42        -30.54         -640
.
.                                                               Inner perimeter
.
create vertex  -118.61        -119.18        -640
create vertex  -120.41        -100.51        -640
create vertex  -128.02        -82.52         -640
### Drawdown 1 ----------------------------------                            Bottom
create vertex  -122.74        -65.34         -640
create vertex  -118.83        -47.34         -640
create vertex  -112.01        -27.11         -640
.
.                                                               Outer perimeter
.
create vertex  -106.85        -122.16        -640
create vertex  -108.78        -102.13        -640
create vertex  -116.94        -82.84         -640
```

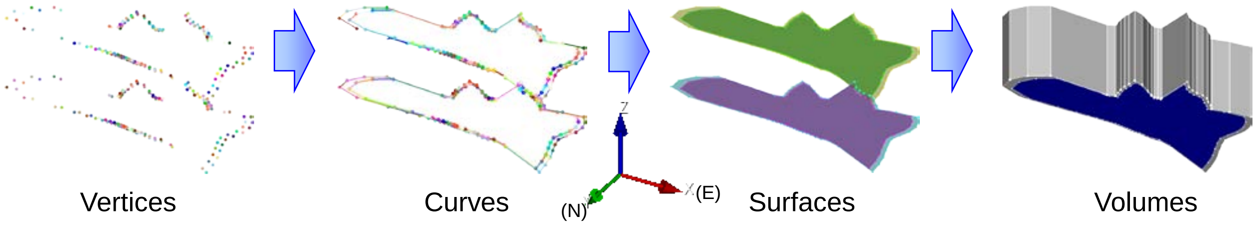


Figure 39: Vertices, curves, surfaces, and volumes of BC-4 column at roof

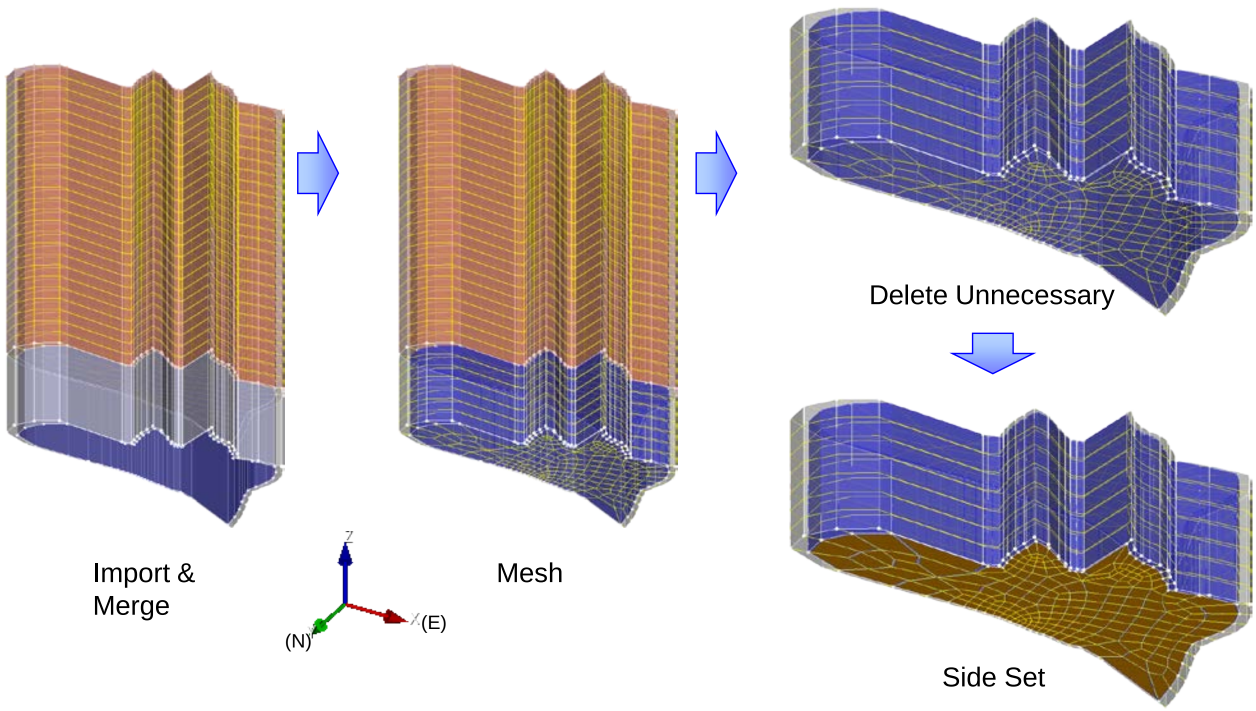


Figure 40: Steps to mesh BC-4 cavern roof in caprock layer

6.2.5. Cavern slice blocks

The BC-4 inside cavern block consists of 51 cavern slice volumes with 20 ft thickness because the elevations of the top and bottom of the block are -660 ft and -1680 ft, respectively. The first BC-4 cavern slice volume under the roof is created through the Cubit journal file in File 32.

`vtx_0660.jou` is shown File 22. The X- and Y- coordinates of the vertices on the top are the same as on the bottom, i.e. the horizontal cross section of the cavern is assumed to be the same with depth in the caprock for simplification.

To create a cavern volume slice inside the cavern, the journal file of `create_vol.jou` (File 11) (replacing 001 by 004) is used as when the previous volumes are created in the overburden layer as shown Figure 41.

To create the mesh in the volumes, **mesh_wall.jou** (File 23) (replacing 001 by 004) is used. Figure 42 shows the steps to mesh BC-4 cavern slice volume. As the first step, the roof block is imported over the cavern slice volume. The bottom surfaces of the roof block and the top surfaces of the slice volume are merged to transfer the mesh. As the next step, the curves on the wall of the slice volumes are meshed with one interval because the thickness of the slice volumes is 20 ft, and then the volumes in the slice block are meshed entirely. As the third step, the imported roof block is deleted. As the last step, the side set is defined as `Sideset 40660` on the inside of outer slice volume to represent the cavern wall. Other 50 cavern slice blocks are meshed through the same steps in **mesh_wall.jou** (File 23) .

The meshed inner and outer volumes are defined as `Element Block 40660` and `Element Block 40661`, respectively. The meshed cavern slice volumes are saved into the storage through the command scripts in **save.jou** (File 21) (replacing 001 by 004).

File 39: vtx_0660.jou

```
# Top elevation        : {TELE=       -640    }ft
# Bottom elevation     : {BELE=       -660    }ft
# Cavern ID    : {CID=004*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         -640
create vertex  -129.78        -49.41         -640
create vertex  -123.42        -30.54         -640
.
.
.
create vertex  -118.61        -119.18        -640
create vertex  -120.41        -100.51        -640
create vertex  -128.02        -82.52         -640
### Drawdown 1 ----------------------------------
create vertex  -122.74        -65.34         -640
create vertex  -118.83        -47.34         -640
create vertex  -112.01        -27.11         -640
.
.
.
create vertex  -106.85        -122.16        -640
create vertex  -108.78        -102.13        -640
create vertex  -116.94        -82.84         -640
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -133.42        -66.20         -660
create vertex  -129.78        -49.41         -660
create vertex  -123.42        -30.54         -660
.
.
.
create vertex  -118.61        -119.18        -660
create vertex  -120.41        -100.51        -660
create vertex  -128.02        -82.52         -660
### Drawdown 1 ----------------------------------
create vertex  -122.74        -65.34         -660
create vertex  -118.83        -47.34         -660
create vertex  -112.01        -27.11         -660
.
.
.
create vertex  -106.85        -122.16        -660
create vertex  -108.78        -102.13        -660
create vertex  -116.94        -82.84         -660
```

60 lines

Inner perimeter

Top

Outer perimeter

Inner perimeter

Bottom

Outer perimeter

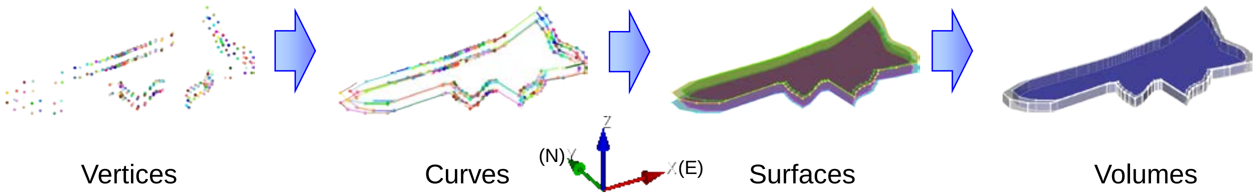


Figure 41: Steps to create BC-4 cavern slice volume whose bottom elevation is -660 ft

File 40: mesh_wall.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ===============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL1} interval 1
mesh volume {VDL0} to {VDL1}
#### Smoothing -----------------------
surface in sdl0b smooth scheme cond
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Sideset ==================================================
sideset {BID+VI0} surface in sdl0w wrt volume {VDL1}
```

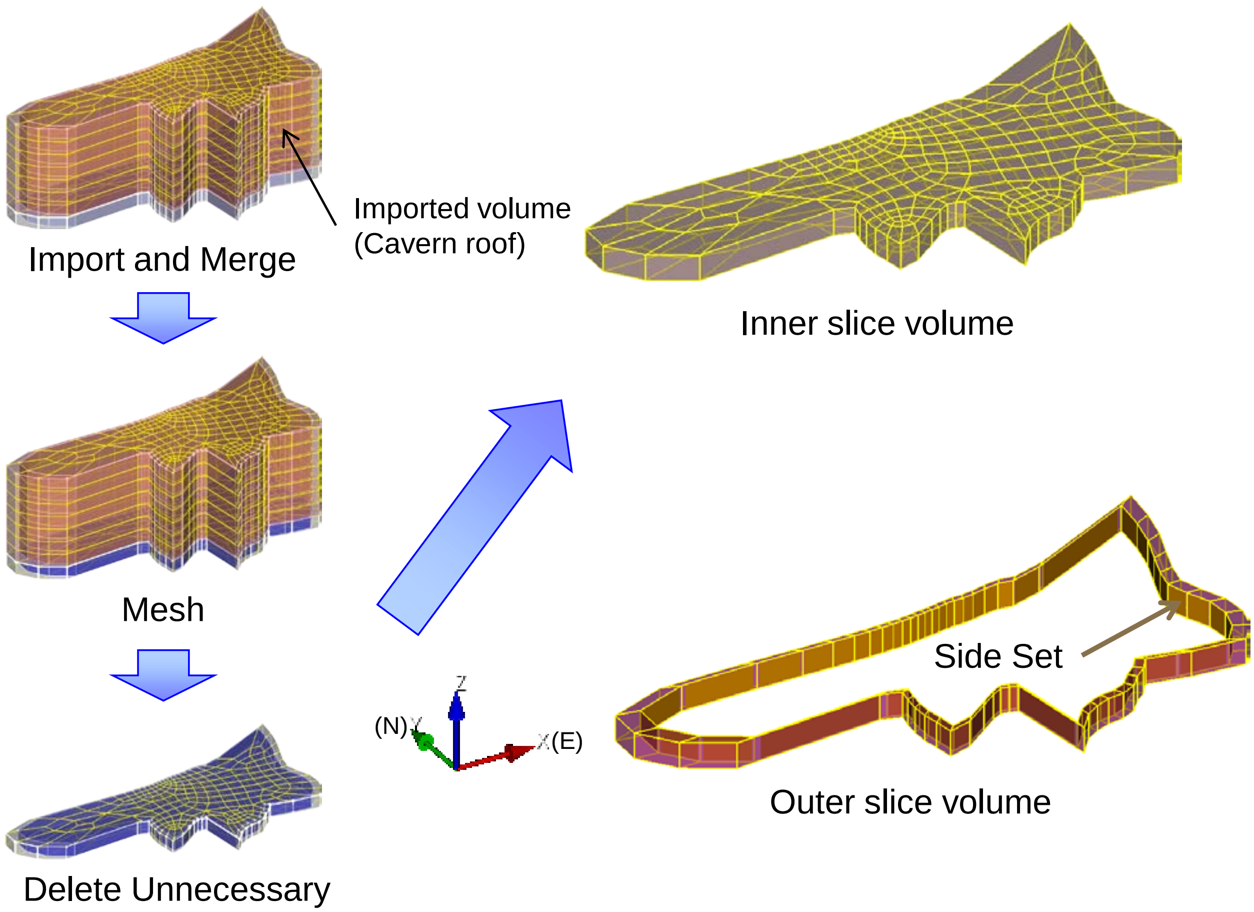


Figure 42: Steps to mesh BC-4 cavern slice volume whose bottom elevation is -660 ft

6.2.6. Floor block

The Cubit journal file `bot_1680_floor.jou` (File 33) creates the cavern floor block. File 41 shows the Cubit journal file to create the vertices for the BC-4 floor block. The elevations of the top and bottom of the roof block are -1660 ft and -1680 ft, respectively. The cavern floor volumes are created using `create_vol.jou` (File 11 replacing 001 with 004) as shown Figure 43.

To create the mesh in the volumes, `mesh_floor.jou` (File 25 replacing 001 with 004) is used. Figure 44 shows the steps to create the mesh into the cavern floor block. As the first step, the cavern slice block over the floor block is imported, and the bottom surfaces of the cavern slice block and the top surfaces of the floor block are merged to transfer the mesh. As the next step, the vertical curves on the floor block are meshed with one interval because the thickness of the floor block is 20 ft, and then the volumes in the floor block are meshed entirely. As the third step, the imported cavern slice block is deleted. As the last step, the side set is defined on the top of the inner volume as `Sideset 41680` to represent the cavern floor.

The meshed inner and outer volumes are defined as `Element Block 41680` and `Element Block 41681`, respectively. The meshed upper salt block is saved through the command scripts in `save.jou` (File 21 replacing 001 with 004).

File 41: vtx_1680.jou

```
# Top elevation        : {TELE=       -1660   }ft
# Bottom elevation     : {BELE=       -1680   }ft
# Cavern ID     : {CID=004*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume    : {VDL0=TNSB+1}
# created 1st drawdown skin volume      : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -172.63        -63.17         -1660
create vertex  -171.51        -55.72         -1660
create vertex  -170.80        -47.89         -1660
.
.                                                    60 lines     Inner perimeter
.
create vertex  -171.00        -85.59         -1660
create vertex  -168.26        -78.33         -1660
create vertex  -171.13        -70.44         -1660
### Drawdown 1 ---------------------------------                                  Top
create vertex  -167.69        -62.89         -1660
create vertex  -166.49        -54.91         -1660
create vertex  -165.73        -46.51         -1660
.
.                                                                 Outer perimeter
.
create vertex  -165.94        -86.93         -1660
create vertex  -163.01        -79.14         -1660
create vertex  -166.08        -70.69         -1660
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -172.63        -63.17         -1680
create vertex  -171.51        -55.72         -1680
create vertex  -170.80        -47.89         -1680
.
.                                                                 Inner perimeter
.
create vertex  -171.00        -85.59         -1680
create vertex  -168.26        -78.33         -1680
create vertex  -171.13        -70.44         -1680
### Drawdown 1 ---------------------------------                                  Bottom
create vertex  -167.69        -62.89         -1680
create vertex  -166.49        -54.91         -1680
create vertex  -165.73        -46.51         -1680
.
.                                                                 Outer perimeter
.
create vertex  -165.94        -86.93         -1680
create vertex  -163.01        -79.14         -1680
create vertex  -166.08        -70.69         -1680
```

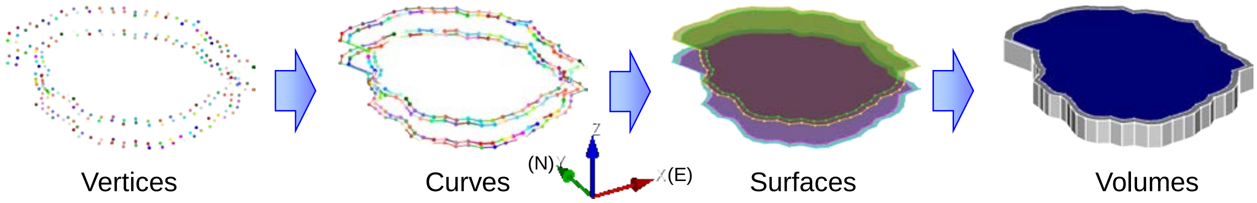


Figure 43: Vertices, curves, surfaces, and volumes at floor of BC-4

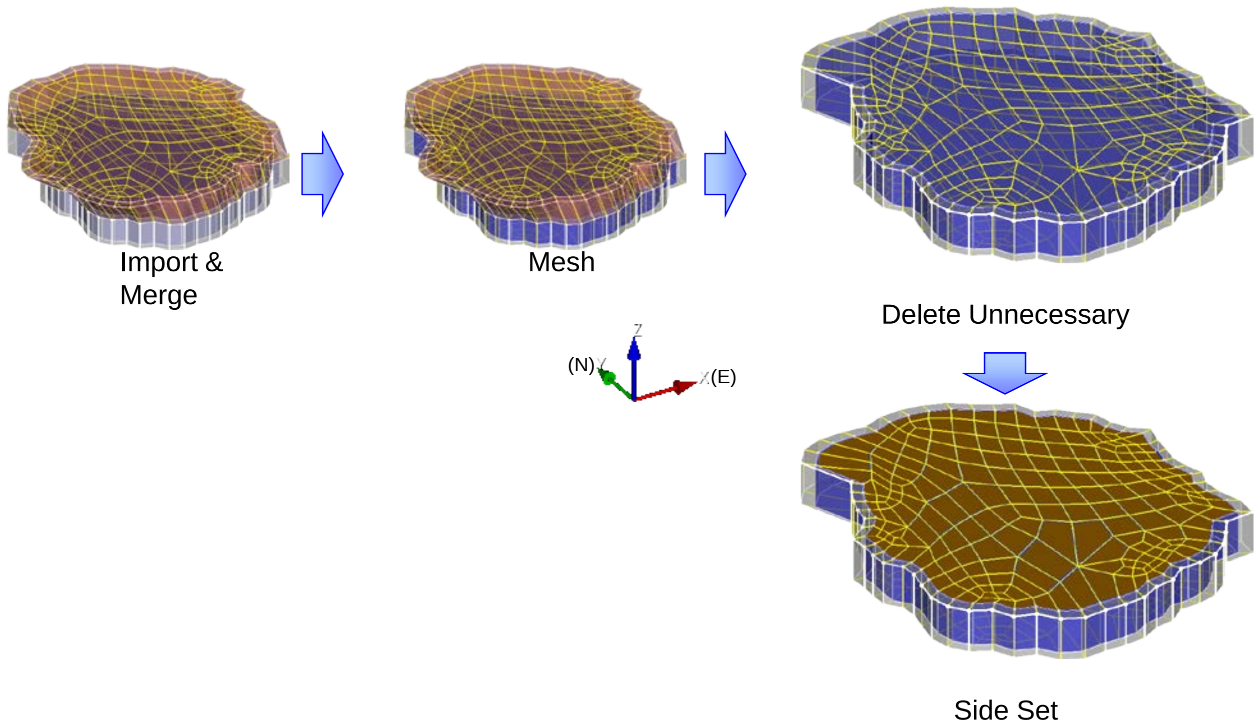


Figure 44: Steps to mesh BC-4 cavern floor whose bottom elevation is -1680 ft

6.2.7. Lower salt block

The Cubit journal file **`bot_2700_below.jou`** (File 34) creates the lower salt block under the cavern floor. **`vtx_2700.jou`** (File 42) is the Cubit journal file to create the vertices for the BC-4 lower salt block. The elevations of the top and bottom of the lower salt block are -1680 ft and -2700 ft, respectively. The volumes in the lower salt block are created using **`create_vol.jou`** (File 11) (replacing 001 with 004) as shown Figure 45.

The horizontal cross-section of the dome is getting larger with depth as shown Figure 9. The top area of BC-4 is about 4 times of the bottom area as shown Figure 34. The area balancing between the dome cross-sections at the top and bottom elevations of BC-4 is needed to avoid creating poor shape mesh on the dome cross-sections outside 26 cavern column. Therefore, the cross-section area of the lower salt block has to be getting larger with depth as shown Figure 45. The bottom area of the lower salt block is larger than the area of the top area of BC4. The lower salt block is a kind of buffer to make an area balance. The bottom salt block, which top and bottom areas are the same, will be created under the lower salt block for BC-4 cavern column.

To create the mesh in the volumes, **`mesh_below_wo_ss.jou`** (File 43) is used. Comparing the previous **`mesh_below_wo_ss.jou`** (File 27), cavern ID 001 is replaced with 004, and the script to define `Nodeset` does not exist. The node set will be defined at the bottom salt block next section. Figure 46 shows the steps to create the mesh into the lower salt block. As the first step, the cavern floor block is imported over the lower salt block, and the bottom surfaces of the floor block and the top surfaces of the lower salt block are merged to transfer the mesh. As the next step, the vertical curves on the lower salt block are meshed with 51 intervals because the height of the lower salt block is 1020 ft, and then the volumes in the lower salt block are meshed entirely. As the third step, the imported floor block is deleted. As the last step, the meshed inner and outer volumes are defined as `Element Blocks 42700` and `42701`, respectively. The meshed lower salt block is saved through the command scripts in **`save_wo_ss.jou`** (File 28) (replacing 001 with 004).

File 42: vtx_2700.jou

```
# Top elevation       : {TELE=       -1680   }ft
# Bottom elevation    : {BELE=       -2700   }ft
# Cavern ID    : {CID=004*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer    : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  -172.63        -63.17         -1680
create vertex  -171.51        -55.72         -1680
create vertex  -170.80        -47.89         -1680
.
.                                                     60 lines      Inner perimeter
.
create vertex  -171.00        -85.59         -1680
create vertex  -168.26        -78.33         -1680
create vertex  -171.13        -70.44         -1680
### Drawdown 1 ----------------------------------                                      Top
create vertex  -167.69        -62.89         -1680
create vertex  -166.49        -54.91         -1680
create vertex  -165.73        -46.51         -1680
.
.                                                                   Outer perimeter
.
create vertex  -165.94        -86.93         -1680
create vertex  -163.01        -79.14         -1680
create vertex  -166.08        -70.69         -1680
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  4.82           -61.24         -2700
create vertex  8.85           -50.07         -2700
create vertex  11.42          -38.32         -2700
.
.                                                                   Inner perimeter
.
create vertex  10.69          -94.87         -2700
create vertex  20.54          -83.97         -2700
create vertex  10.22          -72.15         -2700
### Drawdown 1 ----------------------------------                                      Bottom
create vertex  22.61          -60.82         -2700
create vertex  26.92          -48.84         -2700
create vertex  29.68          -36.25         -2700
.
.                                                                   Outer perimeter
.
create vertex  28.90          -96.88         -2700
create vertex  39.46          -85.20         -2700
create vertex  28.39          -72.52         -2700
```

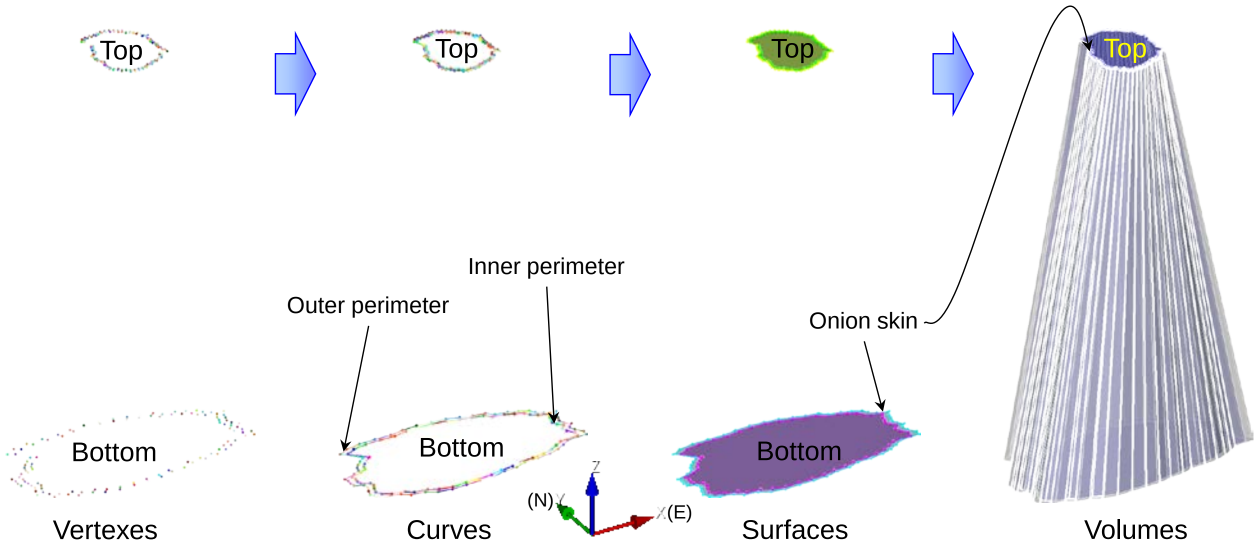


Figure 45: Vertices, curves, surfaces, and volumes for lower salt block of BC-4

File 43: mesh_below_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\cub\bc004_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ----------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
```

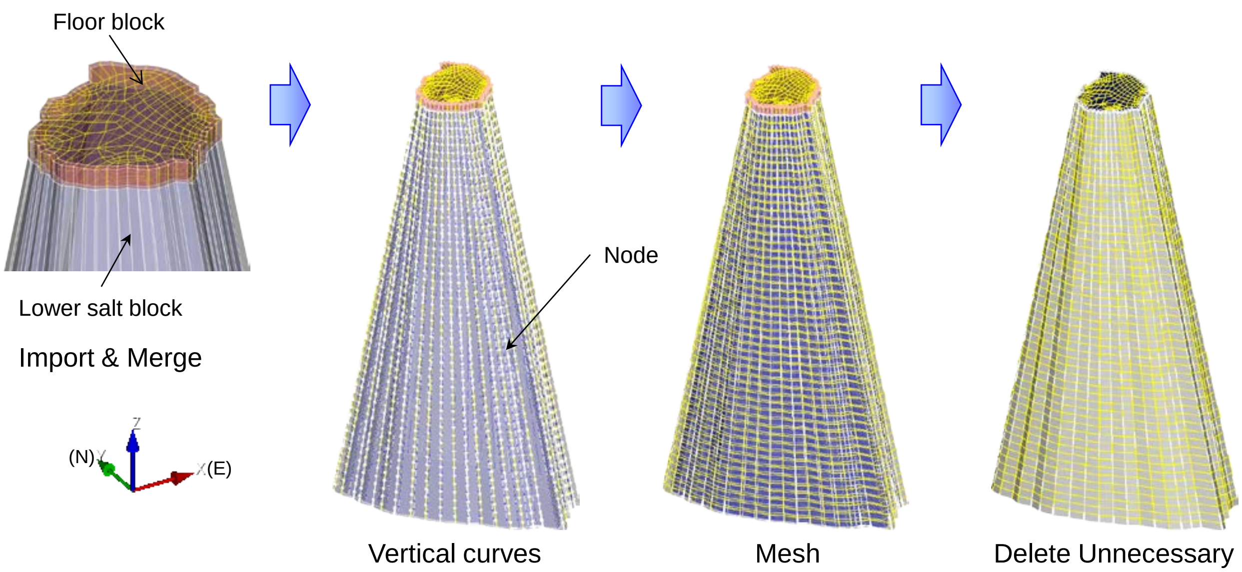


Figure 46: Steps to mesh BC-4 lower salt block whose bottom elevation is -2700 ft

6.2.8. Bottom salt block

The Cubit journal file **`bot_6400_bottom.jou`** (File 35) creates the bottom salt block under the lower salt block. **`vtx_6400.jou`** (File 45) is the Cubit journal file to create the vertices for the BC-4 bottom salt block. The elevations of the top and bottom of the bottom salt block are -2700 ft and -6400 ft, respectively. The volumes in the bottom salt block are created using **`create_vol.jou`** (File 11) (replacing 001 by 004) as shown Figure 47.

To create the mesh in the volumes, **`mesh_bottom_wo_ss.jou`** (File 43) is used. Figure 46 shows the steps to create the mesh into the lower salt block. As the first step, the lower salt block is imported over the bottom salt block, and the bottom surfaces of the lower salt block and the top surfaces of the bottom salt block are merged to transfer the mesh. As the next step, the vertical curves on the bottom salt block are meshed with 185 intervals because the height of the bottom salt block is 3700 ft, and then the volumes in the bottom salt block are meshed entirely. As the third step, the imported lower salt block is deleted. As the last step, the node set on the bottom of the bottom salt block is defined as `Nodeset 40003` which will be added on the bottom node set of the entire model. The meshed inner and outer volumes are defined as `Element Blocks 46400` and `46401`, respectively. The meshed bottom salt block is saved through the command scripts in **`save_wo_ss.jou`** (File 28) (replacing 001 by 004).

File 44: vtx_6400.jou

```
# Top elevation       : {TELE=       -2700   }ft
# Bottom elevation    : {BELE=       -6400   }ft
# Cavern ID    : {CID=004*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=60}
# number of drowdown leaches  : {NDL=1}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer    : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  4.82          -61.24         -2700
create vertex  8.85          -50.07         -2700
create vertex  11.42         -38.32         -2700
.
.                                                  60 lines      Inner perimeter
.
create vertex  10.69         -94.87         -2700
create vertex  20.54         -83.97         -2700
create vertex  10.22         -72.15         -2700
### Drawdown 1 ----------------------------------                                  Top
create vertex  22.61         -60.82         -2700
create vertex  26.92         -48.84         -2700
create vertex  29.68         -36.25         -2700
.
.                                                                Outer perimeter
.
create vertex  28.90         -96.88         -2700
create vertex  39.46         -85.20         -2700
create vertex  28.39         -72.52         -2700
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  4.82          -61.24         -6400
create vertex  8.85          -50.07         -6400
create vertex  11.42         -38.32         -6400
.
.                                                                Inner perimeter
.
create vertex  10.69         -94.87         -6400
create vertex  20.54         -83.97         -6400
create vertex  10.22         -72.15         -6400
### Drawdown 1 ----------------------------------                                  Bottom
create vertex  22.61         -60.82         -6400
create vertex  26.92         -48.84         -6400
create vertex  29.68         -36.25         -6400
.
.                                                                Outer perimeter
.
create vertex  28.90         -96.88         -6400
create vertex  39.46         -85.20         -6400
create vertex  28.39         -72.52         -6400
```

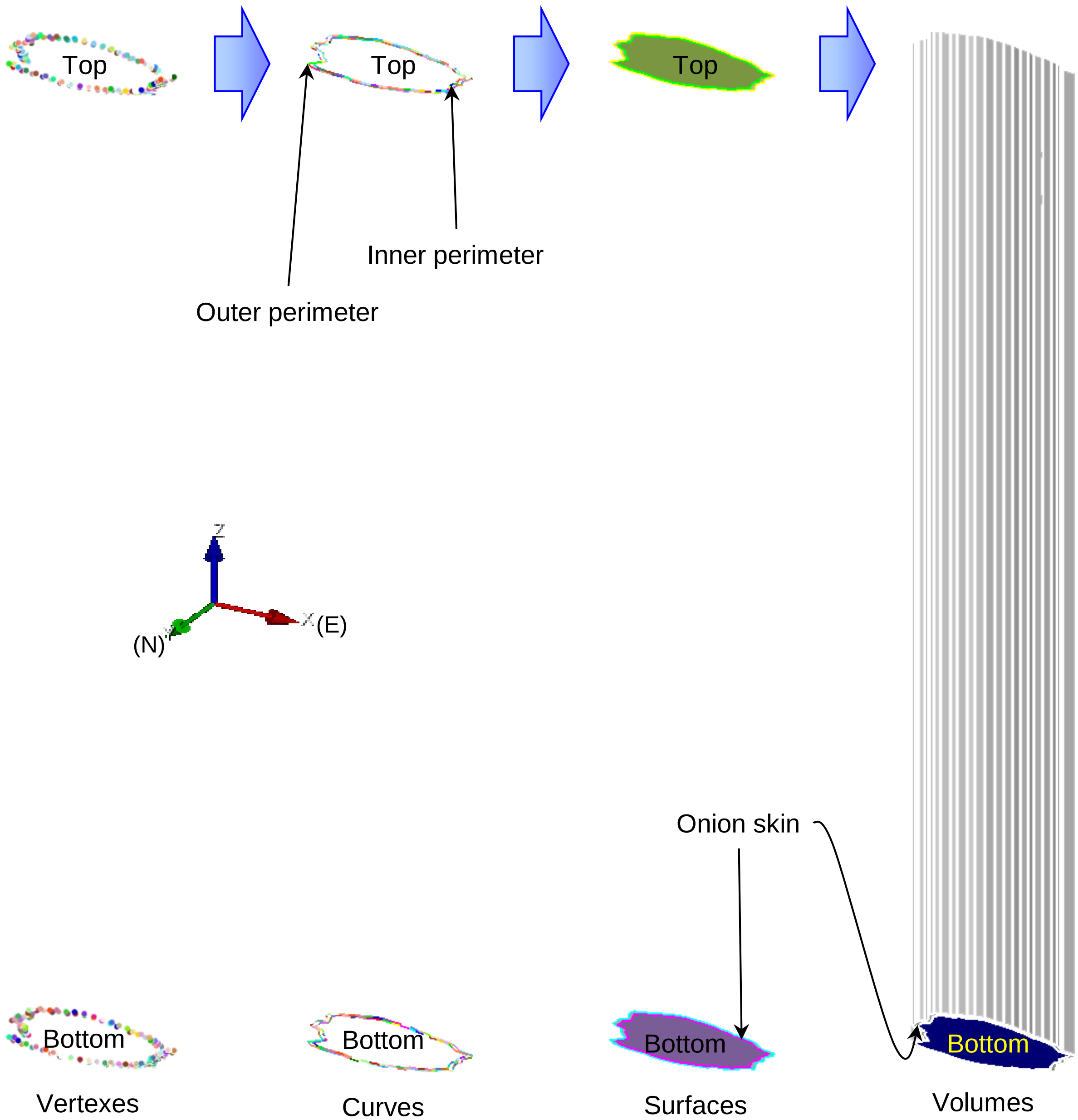


Figure 47: Vertices, curves, surfaces, and volumes for bottom salt block of BC-4

File 45: mesh_bottom_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_1skin.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\cub\bc004_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ---------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
# Define Node Set =====================================================
nodeset {CID+3} surface in bsurf
```

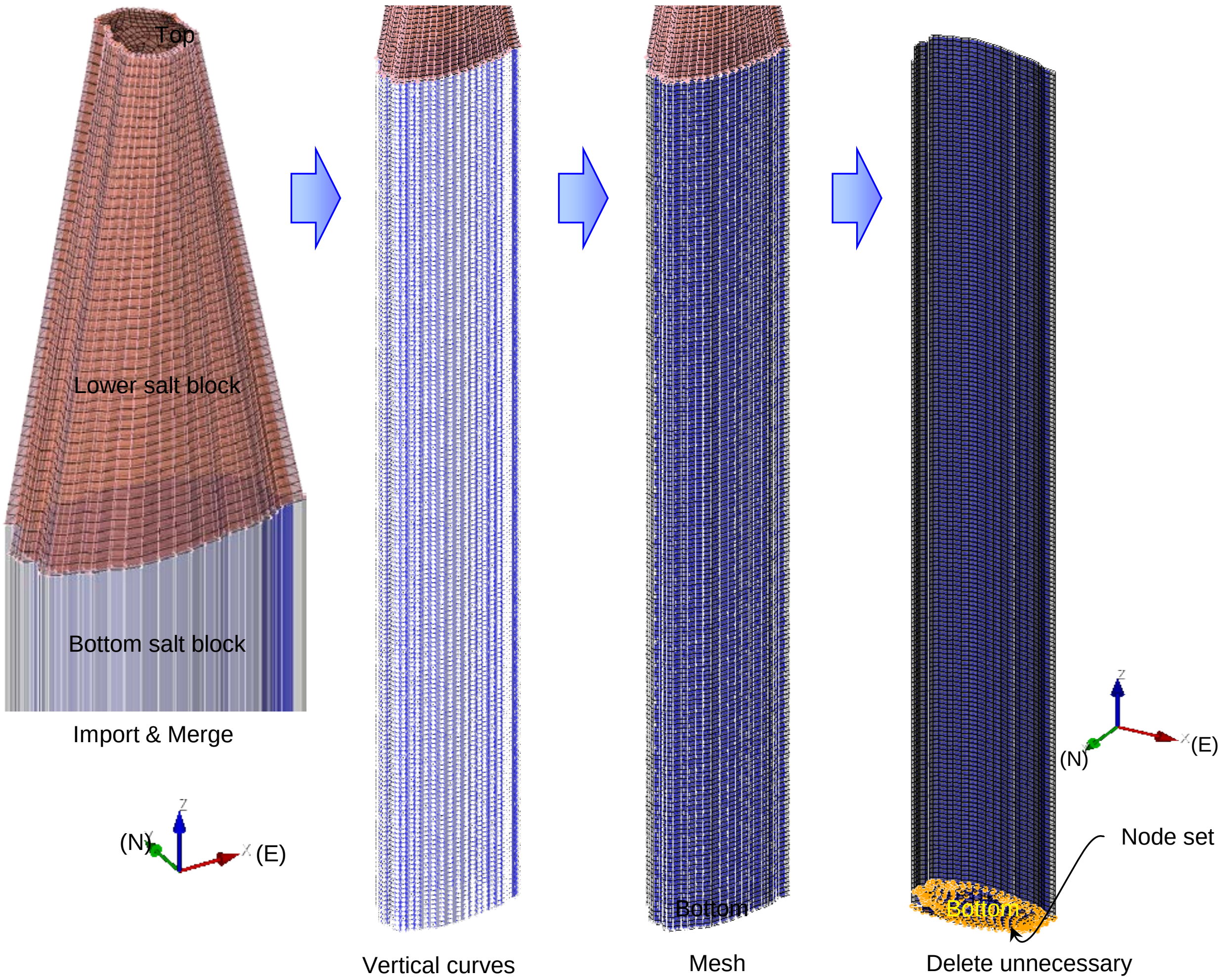


Figure 48: Steps to mesh BC-4 bottom salt block whose bottom elevation is -6400 ft

6.2.9. Cavern column

56 meshed blocks created in Section 6.2.3 through 6.2.8 are assembled into the BC-4 cavern column as shown Figure 49 through the GJOIN process on Redsky. **`bc004.gjn`** (File 46) shows the GJOIN scripts. The Genesis file of BC-4 cavern column is saved as **`bc004.g1`** into the directory of `/fscratch/bypark/BC_sonar/mesh/bc004g1/`. **`bc004.g1`** will be assembled into the entire model mesh of **`bc_20ft.g0`**.

The ID digits hereafter were described in Section 3.5. As the first step, two Genesis files **`dome_500.g0`** and **`dome_640.g0`** are combined with the tolerance of 1.E-02. The inner cavern slice volume in the overburden layer (`Element Block 40500, GJOIN ID 1`) is assigned to the overburden block in the entire model as `Element Block 2004`. The outer cavern skin slice volume in the overburden layer (`Element Block 40501`) is combined to `Element Block 2004`. The inner cavern roof volume in the caprock layer (`Element Block 40640, GJOIN ID 3`) is assigned to the caprock block in the entire model as `Element Block 30041`. The cavern roof is regarded as cavern onion skin. The outer cavern skin slice volume in the caprock layer (`Element Block 40641`) is combined to `Element Block 30041`. The side set on the bottom of the inner cavern roof volume

(`Sideset 40640, GJOIN ID 1`) is assigned to the side set in the entire model as `Sideset 40` which represents the ceiling of the cavern.

As the second step, the Genesis file **`bc004_660.g0`** is combined to the combined two Genesis files above. The inner cavern slice volume in the caprock layer (`Element Block 40660, GJOIN ID 3`) is assigned to the caprock block in the entire model as `Element Block 30040`. The outer cavern skin slice volume in the caprock layer (`Element Block 40661`) is combined to `Element Block 30041`. The side set on the inside of the outer cavern skin slice volume (`Sideset 40660`) is assigned to the side set in the entire model as `Sideset 40` which represents the wall of the cavern. Therefore, `Sideset 40` represents the inside surface of the cavern because the side sets for the ceiling above, the wall, and the floor below are combined into `Sideset 40` together.

As the third step, the Genesis file **`bc004_680.g0`** is combined to the combined three Genesis files above. The inner cavern slice volume in the interbed layer (`Element Block 40680, GJOIN ID 4`) is assigned to the interbed block in the entire model as `Element Block 80040`. The outer cavern skin slice volume in the interbed layer (`Element Block 40681, GJOIN ID 5`) is combined to `Element Block 80041`. The side set on the inside of the outer cavern skin slice volume (`Sideset 40680`) is assigned to the side set in the entire model as `Sideset 40`.

As the fourth step, the Genesis file **`bc004_0700.g0`** is combined to the combined four Genesis files above. The inner cavern slice volume in the salt cavern layer (`Element Block 40700, GJOIN ID is 6`) is assigned to the salt block in the entire model as `Element Block 10040`. The outer cavern skin slice volume in the roof layer (`Element Block 40701, GJOIN ID 7`) is combined to `Element Block 10041`. The side set on the inside of the outer cavern skin slice volume (`Sideset 40700`) is assigned to the side set in the entire model as `Sideset 40`.

As the fifth step, the Genesis file **`bc004_0720.g0`** is combined to the combined five Genesis files above. The inner cavern slice volume in the cavern layer (`Element Block 40720`) is assigned to the salt block in the entire model as `Element Block 10040`. The outer cavern skin slice volume in the cavern layer (`Element Block 40721`) is combined to `Element Block 10041`. The side set on the inside of the outer cavern skin slice volume (`Sideset 10720`) is assigned to the side set in the entire model as `Sideset 40`.

In the same manner as the fifth step, the geneses files from **`bc004_0740.g0`** through **`bc004_1660.g0`** are combined.

As the next step, the Genesis file **`bc004_1680.g0`** is combined to the combined 53 Genesis files above (BC-4 cavern column consists of 56 cavern slice blocks). The inner cavern slice volume in the floor layer (`Element Block 41680`) is assigned to the salt block in the entire model as `Element Block 10041`. The cavern floor is regarded as cavern onion skin. The outer cavern skin slice volume in the floor layer (`Element Block 41681`) is also combined into `Element Block 10041`. The side set on the top of the inner cavern slice volume (`Sideset 41680`) is assigned into `Sideset 40` which represents the inside of the cavern in the entire model.

As the next step, the Genesis file **`bc004_2700.g0`** is combined to the combined 54 Genesis files above. The inner cavern slice volume in the lower salt layer (`Element Block 42700, GJOIN ID 8`) is assigned to the salt block in the entire model as `Element Block 1004`. The outer cavern skin slice volume in the lower salt layer (`Element Block 42701`) is also combined into `Element Block 1004`.

As the last step, the Genesis file **`bc004_6400.g0`** is combined to the combined 55 Genesis files above. The inner cavern slice volume in the bottom salt layer (`Element Block 46400`) is assigned to the salt block in the entire model as `Element Block 1004`. The outer cavern skin slice volume in the bottom salt layer (`Element Block 46401`) is combined to `Element Block 1004`. The node set on the bottom of the bottom salt block (`Nodeset 40003, GJOIN ID 1`) is redefined as `Nodeset 3004` which represents the bottom boundary of BC-4 cavern column.

File 46: bc004.gjn

```
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_500.g0
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_640.g0
comb
1.00E-02
no
blocks
id 1 2004
id 3 30041
combine 2004 40501
combine 30041 40641
up
sset
id 1 40
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_660.g0
comb
1.00E-02
no
blocks
id 3 30040
combine 30041 40661
up
sset
combine 40 40660
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_680.g0
comb
1.00E-02
no
blocks
id 4 80040
id 5 80041
up
sset
combine 40 40680
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_700.g0
comb
1.00E-02
no
blocks
id 6 10040
id 7 10041
up
sset
combine 40 40700
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_720.g0
comb
1.00E-02
no
blocks
combine 10040 40720
combine 10041 40721
up
sset
combine 40 40720
up

(To be continued)
```

```
.
.
.

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_1660.g0
comb
1.00E-02
no
blocks
combine 10040 41660
combine 10041 41661
up
sset
combine 40 41660
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_1680.g0
comb
1.00E-02
no
blocks
combine 10041 41680
combine 10041 41681
up
sset
combine 40 41680
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_2700.g0
comb
1.00E-02
no
blocks
id 8 1004
combine 1004 42701
up

add
/fscratch/bypark/BC_sonar/mesh/bc004/bc004_6400.g0
comb
1.00E-02
no
blocks
combine 1004 46400
combine 1004 46401
up
nset
id 1 3004
up

finish
/fscratch/bypark/BC_sonar/mesh/bc004g1/bc004.g1
```

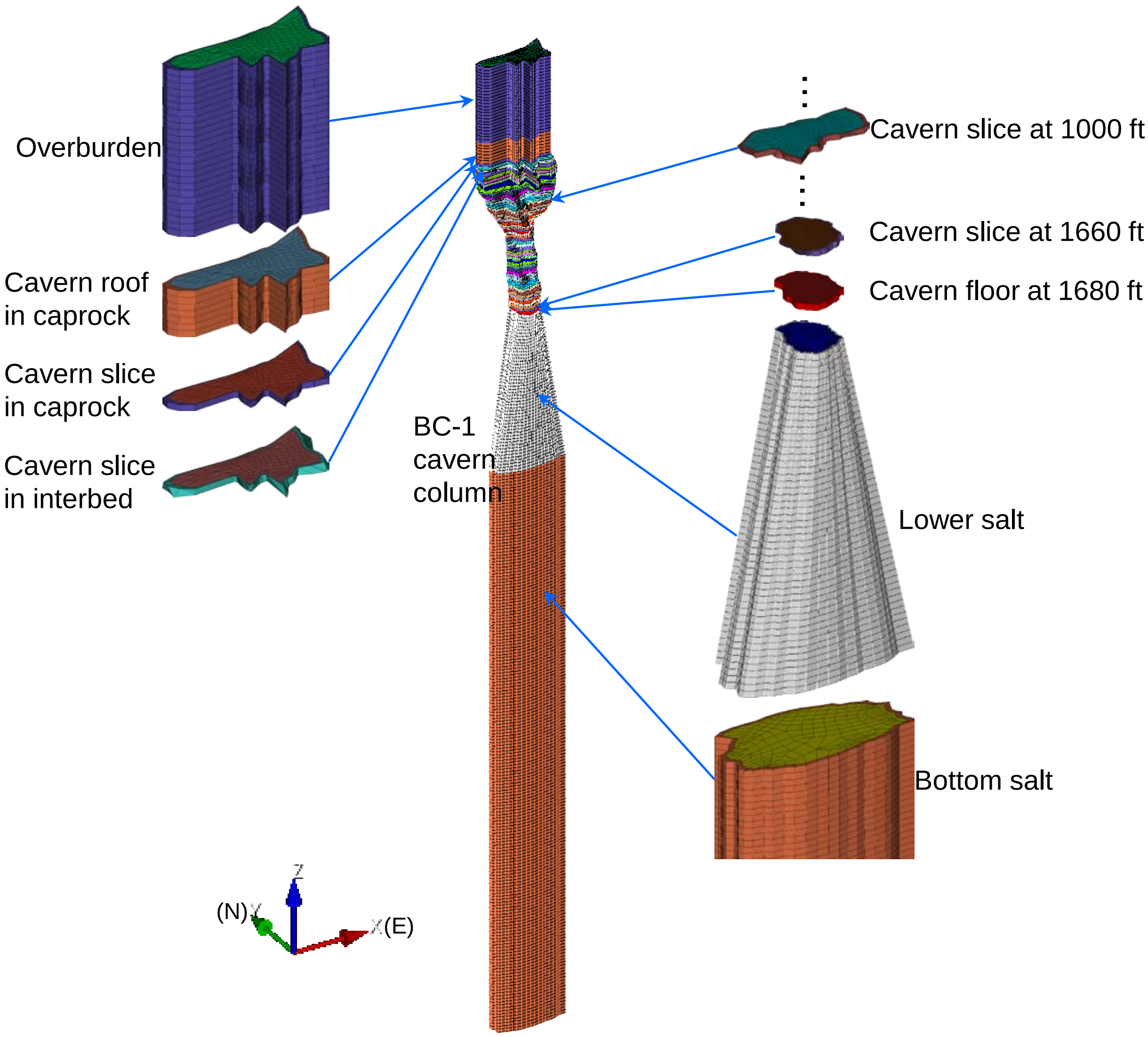


Figure 49: BC-4 cavern column

6.3. BC-7

6.3.1. Field data

Cavern 7 was drilled in 1942 to a depth of 1951 ft. The depth to the original top of the cavern is not known. The cavern volume was calculated from production data to be 2.9 MMB. Normal brining operations continued into the early 1950's when cavern pressure was lost. It is assumed that pressure was lost when the cavern roof was leached to the top of the salt. Brining continued by the airlift method until January, 1954 when the cavern collapsed. This resulted in the formation of a crater about 800 ft in diameter which filled with water and is now called Cavern Lake. Cavern collapse resulted from leaching of the salt to the salt/caprock contact followed by the failure of the caprock and overlying sediments [Hogan, 1980]. Cavern 7 collapsed began at the well head and filled with overburden [Hogan, 1980; Neal et al., 1993].

In this model, the elevation of the top of BC-7 is assumed the same as the elevation of the caprock top, -500 ft. then the height of the cavern is calculated to be 1451 ft. Thus, the diameter of BC-7 is calculated to be 120 ft.

The coordinates of BC-7 well is estimated to be (-719, 1710) from Figure 2. The measured depth of the lake was -100 ft in 1956 [The Aerospace Corporation, 1980]. The lake depth (about 100 ft) is small relative to the model height (6400 ft) and the lake diameter (about 800 ft) is large relative to the lake depth, so the lake would be regarded as a part of the surface, so the lake geometry is simplified flat as the surface in this model.

6.3.2. Mesh generation

File 47 shows the Cubit command scripts to generate the meshed cavern column of BC-7 as shown Figure 50. The cavern is assumed to be cylinder shape with 120 ft diameter. The cavern roof in the caprock layer is assumed to be a frustum with 40 ft top diameter. The cylinder with 40 ft diameter penetrates the overburden layer from the surface to the caprock roof. The cavern slice blocks in the caprock and interbed layers are separated from the cavern body in salt because the material properties are not salt. The cavern height is 1460 ft rather than 1451 ft because the model meshes are discretized by 20 ft element level. The frustum shape with 120 ft and 40 ft diameters is used for the cavern roof and floor, so the amount of the cavern volume is close to 2.9 MMB. The lower salt frustum and bottom salt cylinder with the diameter of cavern body are constructed for the dome area balancing with depth.

The skins enclosed the cavern column are constructed with 10 ft thickness. The side sets and node set are contained into the cavern column, so GJOIN process is not needed. The cavern column and the skin blocks are stored into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\`. The cavern skin blocks will be used for punching the dome slice blocks to make the cavern column hole.

File 47: Cubit journal file for BC-7

```
# X-coordinate of the well: {X_well= -719}
# Y-coordinate of the well: {Y_well= 1710}
# X-coordinate of the dome center: {X_dome= 0}
# Y-coordinate of the dome center: {Y_dome= 0}
# X-coordinate of the well in model: {X_007=X_well-X_dome}
# Y-coordinate of the well in model: {Y_007=Y_well-Y_dome}
# Diameter of BC-7: {D_007=120} ft
# Thickness of cavern skin: {T_skin=10} ft
# Radius of BC-7: {R0_007=D_007/2}
# Radius of BC-7 skin: {R1_007=R0_007+T_skin}
# Radius of neck at surface: {R0_surf=R0_007/3}
# Radius of neck skin at surface: {R1_surf=R0_surf+T_skin}
# Radius of neck at cavern bottom: {R0_cb=R0_surf}
# Radius of neck skin cavern bottom: {R1_cb=R1_surf}
# Height of cavern roof and floor: {H_roof=140} {H_floor=40}
# Z-coordinate of surface: {Z_surf=0.000} ft
# Z-coordinate of overburden bottom: {Z_OBB=-500}
# Z-coordinate of caprock bottom: {Z_CRB=-660}
# Z-coordinate of interbed bottom: {Z_IBB=-680}
# Z-coordinate of model bottom: {Z_MDB=-6400}
# Z-coordinate of BC-7 body top: {Z_btop=Z_OBB-H_roof} ft
# Z-coordinate of BC-7 body bottom: {Z_bbot=-1920} ft
# Height of BC-7 body: {H_007=Z_btop-Z_bbot}
# Z-coordinate of BC-7 body center: {Z_007=Z_btop-H_007/2}
# Z-coordinate of roof center: {Z_roof=Z_btop+H_roof/2}
# Z-coordinate of floor center: {Z_floor=Z_bbot-H_floor/2}
# Height of neck: {H_neck=-Z_OBB}
# Z-coordinate of neck center: {Z_neck=Z_surf-H_neck/2}
# Z-coordinate of lower salt top: {Z_lst=Z_bbot-H_floor}
# Height of lower salt: {H_lower=100}
# Z-coordinate of lower salt bottom: {Z_lsb=Z_lst-H_lower}
# Z-coordinate of lower salt center: {Z_lower=Z_lst-H_lower/2}
# Z-coordinate of bottom salt top: {Z_bst=Z_lsb}
# Z-coordinate of bottom salt bottom: {Z_bsb=Z_MDB}
# Height of bottom salt: {H_bottom=Z_bst-Z_bsb}
# Z-coordinate of bottom salt center: {Z_bottom=Z_bst-H_bottom/2}
# ==================================================================
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
Logging Errors on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\err\bc007.err")}
Set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\log\bc007.log")}
# CREATE VOLUMES====================================================
## Create neck ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create cylinder height {H_neck} radius {R0_surf}
volume {V_neck=V_ls+1} move x {X_007} y {Y_007} z {Z_neck}
### Create neck skin ----------------------------
create cylinder height {H_neck} radius {R0_surf}
create cylinder height {H_neck} radius {R1_surf}
subtract volume {V_neck+1} from volume {V_neck+2}
volume {V_ns=V_neck+2} move x {X_007} y {Y_007} z {Z_neck}
## Create cavern roof ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create frustum height {H_roof} radius {R0_007} top {R0_surf}
volume {V_roof=V_ns+1} move x {X_007} y {Y_007} z {Z_roof}
### Create cavern roof skin ---------------------
create frustum height {H_roof} radius {R0_007} top {R0_surf}
create frustum height {H_roof} radius {R1_007} top {R1_surf}
subtract volume {V_roof+1} from volume {V_roof+2}
volume {V_rs=V_roof+2} move x {X_007} y {Y_007} z {Z_roof}
## Create cavern body ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create cylinder height {H_007} radius {R0_007}
volume {V_body=V_rs+1} move x {X_007} y {Y_007} z {Z_007}
### Create body skin ----------------------------
create cylinder height {H_007} radius {R0_007}
create cylinder height {H_007} radius {R1_007}
subtract volume {V_body+1} from volume {V_body+2}
volume {V_bs=V_body+2} move x {X_007} y {Y_007} z {Z_007}
## Create cavern body in caprock, interbed and salt ~~~~~~~
webcut volume {V_body} {V_bs} with plane zplane offset {Z_CRB}
webcut volume {V_body+3} {V_bs+2} with plane zplane offset {Z_IBB}

(To be continued)
```

```
## Create cavern floor ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create frustum height {H_floor} radius {R0_cb} top {R0_007}
volume {V_floor=V_bs+5} move x {X_007} y {Y_007} z {Z_floor}
### Create cavern roof skin ---------------------
create frustum height {H_floor} radius {R0_cb} top {R0_007}
create frustum height {H_floor} radius {R1_cb} top {R1_007}
subtract volume {V_floor+1} from volume {V_floor+2}
volume {V_fs=V_floor+2} move x {X_007} y {Y_007} z {Z_floor}
## Create lower salt ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create frustum height {H_lower} radius {R0_007} top {R0_cb}
volume {V_lower=V_fs+1} move x {X_007} y {Y_007} z {Z_lower}
### Create lower salt skin ---------------------
create frustum height {H_lower} radius {R0_007} top {R0_cb}
create frustum height {H_lower} radius {R1_007} top {R1_cb}
subtract volume {V_lower+1} from volume {V_lower+2}
volume {V_lss=V_lower+2} move x {X_007} y {Y_007} z {Z_lower}
## Create bottom salt ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create cylinder height {H_bottom} radius {R0_007}
volume {V_bottom=V_lss+1} move x {X_007} y {Y_007} z {Z_bottom}
### Create lower salt skin ---------------------
create cylinder height {H_bottom} radius {R0_007}
create cylinder height {H_bottom} radius {R1_007}
subtract volume {V_bottom+1} from volume {V_bottom+2}
volume {V_bss=V_bottom+2} move x {X_007} y {Y_007} z {Z_bottom}
# MERGE =============================================================
imprint all
# if there are not duplicated volumes, no warnings
merge all
# MESH ==============================================================
# Number of intervals on perimeter: {NIP=18}
# Thickness of one level = {TL=20} ft
## Mesh neck ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh horizontal ----------------------------
surface 3 12 interval {NIP}
mesh surface 3 12
### mesh vertical ------------------------------
surface 1 7 interval {H_neck/TL}
mesh surface {S_neck=1} {S_ls=S_neck+6}
mesh volume {V_neck} {V_ls}
## Mesh roof ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_roof=S_neck+12} {S_rs=S_roof+6} interval {H_roof/TL}
mesh surface {S_roof} {S_rs}
mesh volume {V_roof} {V_rs}
## Mesh body in caprock ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_bcr=38} {S_bcrs=S_bcr+5} interval {(Z_OBB-Z_CRB-H_roof)/TL}
mesh surface {S_bcr} {S_bcrs}
mesh volume {V_bcr=V_body} {V_bcrs=V_bs}
## Mesh body in interbed ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_bib=S_bcrs+5} {S_bibs=S_bib+5} interval {(Z_CRB-Z_IBB)/TL}
mesh surface {S_bib} {S_bibs}
mesh volume {V_bib=V_bcr+3} {V_bibs=V_bcrs+2}
## Mesh body in cavern ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_bcv=S_bib+2} {S_bcvs=S_bcv+6} interval {(Z_IBB-Z_bbot)/TL}
mesh surface {S_bcv} {S_bcvs}
mesh volume {V_bcv=V_bib+2} {V_bcvs=V_bibs+2}
## Mesh floor ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_floor=S_bib+9} {S_fs=S_floor+6} interval {H_floor/TL}
mesh surface {S_floor} {S_fs}
mesh volume {V_floor} {V_fs}
## Mesh lower salt ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_lower=S_floor+12} {S_lss=S_lower+6} interval {H_lower/TL}
mesh surface {S_lower} {S_lss}
mesh volume {V_lower} {V_lss}
## Mesh bottom salt ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### mesh vertical ------------------------------
surface {S_bottom=S_lower+12} {S_bss=S_bottom+6} interval {H_bottom/TL}
mesh surface {S_bottom} {S_bss}
mesh volume {V_bottom} {V_bss}

(To be continued)
```

```
# BLOCK, SIDESET, NODESET ==========================================
## Define block ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
block 20070 volume {V_neck}
block 20071 volume {V_ns}
block 30070 volume {V_roof} {V_bcr}
block 30071 volume {V_rs} {V_bcrs}
block 80070 volume {V_bib}
block 80071 volume {V_bibs}
block 10070 volume {V_bcv} {V_floor}
block 10071 volume {V_bcvs} {V_fs}
block 1007  volume {V_lower} {V_bottom} {V_lss} {V_bss}
## Define Sideset ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
sideset 70  surface  1 wrt volume   3 # wall of neck in overburden
sideset 703 surface 13 wrt volume   6 # inclined roof of cavern in caprock
sideset 70  surface 38 wrt volume   9 # wall of cavern in caprock
sideset 70  surface 48 wrt volume  11 # wall of cavern in interbed
sideset 70  surface 50 wrt volume  13 # wall of cavern in salt
sideset 701 surface 57 wrt volume  16 # inclined floor of cavern in salt
sideset 709 surface 58 wrt volume  17 # floor of cavern in salt
## Define Nodeset ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
nodeset 3007 surface 82 91
# SAVE ============================================================
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\abs\bc007.abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\g1\bc007.g1")} overwrite
echo off
set  logging  on  file  {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\abs\bc007_abstract.txt")}
resume
quality volume all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007.cub")} overwrite
set logging off
echo on
delete volume 1 4 7 20 10 12 14 17
delete block all
delete sideset all
delete nodeset all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub")} overwrite
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\g1\bc007_skn.g1")} overwrite
delete volume all except 3
volume 3 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_500_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 6
volume 6 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_640_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 9
volume 9 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_660_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 11
volume 11 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_680_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 13
volume 13 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_1920_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 16
volume 16 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_1960_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 19
volume 19 id 22 # because imported volume ID = 22 for BC-7 in define_parameters.jou
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_2060_skn.cub")} overwrite
open           "C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_skn.cub
delete volume all except 22
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_6400_skn.cub")} overwrite
```

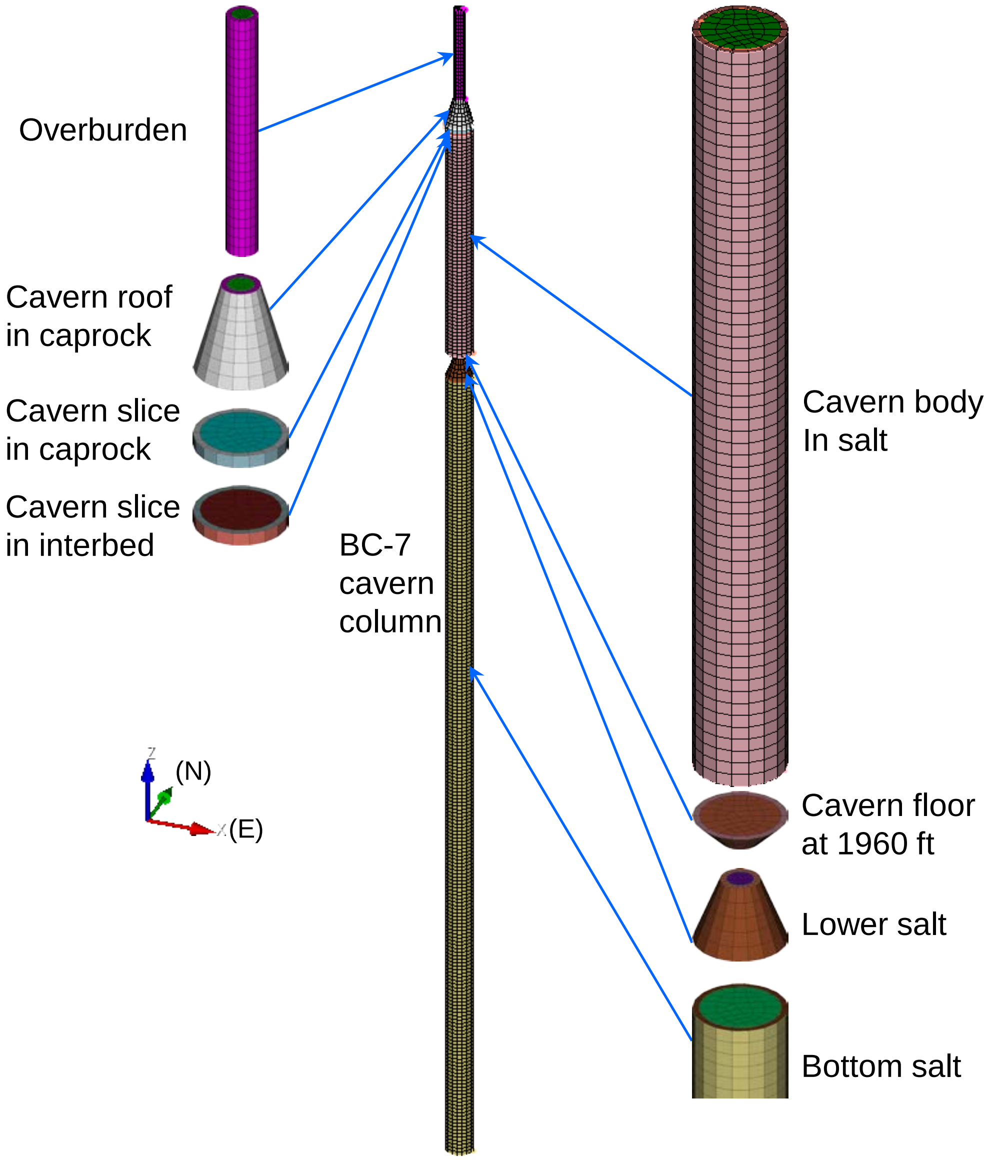


Figure 50: Cavern column of BC-7

6.4. BC-18

BC-18 is selected to describe the mesh generation procedure for the SPR caverns. A similar methodology is used for other SPR caverns. BC-18 has six skins to consider five drawdown leaches. The steps for BC-15 and BC-17 are the same as BC-18 except four skins instead of six skins. The steps for BC-20 are the same as BC-18 except one skin instead of six skins.

6.4.1. Data conversion

Figure 51 shows the sonar image and resampled nodes for BC-18. Each node has X-, Y-, Z-coordinates. The node coordinate data are converted into the vertices data with the Cubit input format through MS Excel manipulation as mentioned in Section 6.1.1.

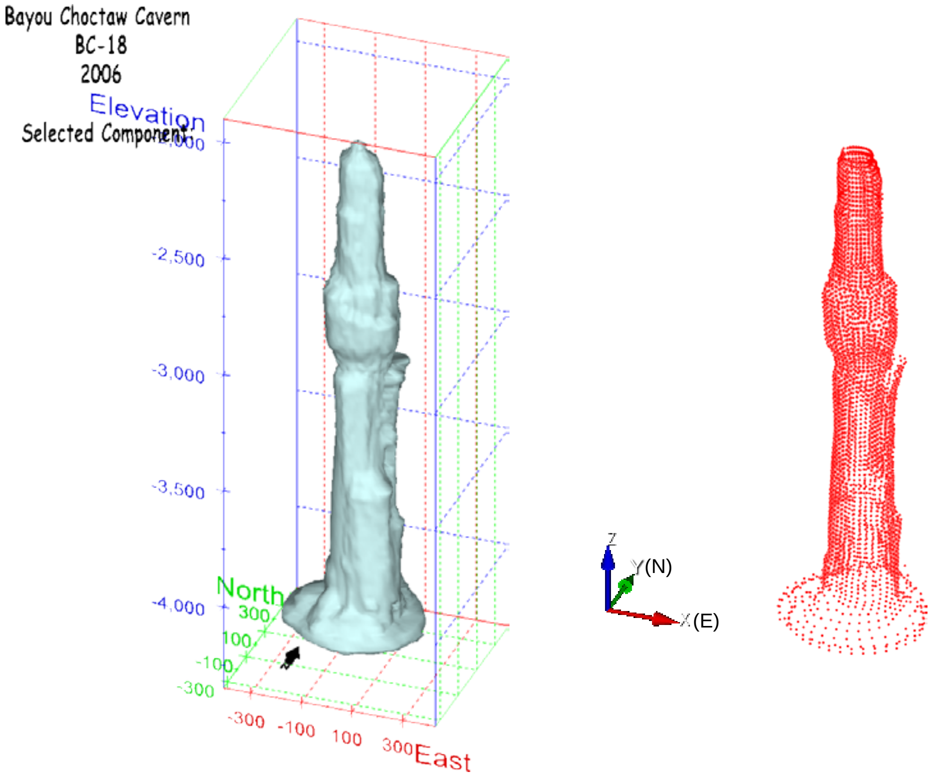


Figure 51: Sonar image (left) and resampled nodes from the sonar image for BC-18

6.4.2. Cubit batch files

File 48 shows the Cubit batch run script for BC-18. As the first step, the sub-Cubit journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_sub\`. As the next step, the vertex journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_vtx\`. As the third step, the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou` and then Cubit batch commands are executed. Meshed 107 cavern slice blocks are created after a series of Cubit batch journal files (File 48) execute completely. As the last step, the sub-Cubit journal files and vertex journal files are returned to the original storage directories, respectively.

The overburden, caprock, and interbed blocks are constructed using **`bot_0500_surface.jou`**, **`bot_0660_above.jou`**, and **`bot_0680_above.jou`** (File 2, File 4, and File 5) used in BC-1. The roof block is constructed with **`bot_2160_roof.jou`** which 1040 in **`bot_1040_roof.jou`** (File 6) is replaced with 2160. The floor block is constructed by using **`bot_4180_floor.jou`** which 1840 in **`bot_1840_floor.jou`** (File 8) is replaced with 4180. The lower salt block is constructed by using **`bot_6400_below.jou`** (File 9).

File 48: Cubit batch run script for BC018

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho bot_0500_surface.jou
Cubit –batch –nographics –noecho bot_0660_above.jou
Cubit –batch –nographics –noecho bot_0680_above.jou
Cubit –batch –nographics –noecho bot_2140_above.jou
Cubit –batch –nographics –noecho bot_2160_roof.jou
Cubit –batch –nographics –noecho bot_2180.jou
Cubit –batch –nographics –noecho bot_2200.jou
Cubit –batch –nographics –noecho bot_2220.jou
Cubit –batch –nographics –noecho bot_2240.jou
Cubit –batch –nographics –noecho bot_2260.jou
Cubit –batch –nographics –noecho bot_2280.jou
Cubit –batch –nographics –noecho bot_2300.jou
Cubit –batch –nographics –noecho bot_2320.jou
Cubit –batch –nographics –noecho bot_2340.jou
Cubit –batch –nographics –noecho bot_2360.jou
Cubit –batch –nographics –noecho bot_2380.jou
Cubit –batch –nographics –noecho bot_2400.jou

.
.
.

Cubit –batch –nographics –noecho bot_3900.jou
Cubit –batch –nographics –noecho bot_3920.jou
Cubit –batch –nographics –noecho bot_3940.jou
Cubit –batch –nographics –noecho bot_3960.jou
Cubit –batch –nographics –noecho bot_3980.jou
Cubit –batch –nographics –noecho bot_4000.jou
Cubit –batch –nographics –noecho bot_4020.jou
Cubit –batch –nographics –noecho bot_4040.jou
Cubit –batch –nographics –noecho bot_4060.jou
Cubit –batch –nographics –noecho bot_4080.jou
Cubit –batch –nographics –noecho bot_4100.jou
Cubit –batch –nographics –noecho bot_4120.jou
Cubit –batch –nographics –noecho bot_4140.jou
Cubit –batch –nographics –noecho bot_4160.jou
Cubit –batch –nographics –noecho bot_4180_floor.jou
Cubit –batch –nographics –noecho bot_6400_below.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\vtx\
```

6.4.3. Block in overburden layer

The block in overburden layer is created through the Cubit journal file, **`bot_0500_surface`** (File 2) like BC-1. **`vtx_500.jou`** (File 49) is the Cubit command journal file to create the vertices for the BC-18 cavern slice block in the overburden layer. The elevations of the top and bottom of the block are zero ft and -500 ft, respectively. BC-18 consists of 36 vertices on a perimeter of the cavern wall. As mentioned in Section 3.1, BC-18 considers six onion skin as shown in Figure 52. The coordinate values of the first through sixth perimeters vertices (`Drawdown 1 through Drawdown 6`) in File 49 are calculated using Eq. (4). The descriptions of parameters for APREPRO process are listed in Table 3.

`create_vol.jou` (File 50) is used to create the cavern column block in the overburden layer. The parameters and their descriptions are listed in Table 3. One cavern volume and six onion skins volumes will be created. Error and logging messages will be recoded into **`bc018_0500.err`** and **`bc018_0500.log`** in the following directory, respectively:

```
C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\err\
C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\log\
```

mesh_surface.jou (File 51) is used to mesh the volumes constructed using **create_vol.jou** (File 50). **define_group_6dd.jou** (File 52) is executed to group specific curves and surfaces as naming in Table 4.

Figure 53 shows the steps to create mesh into the volume. The top surface of the inner volume (`Drawdown 0`) is meshed using the following scripts:

```
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
```

The top surface of the first onion skin (Drawdown 1) is meshed through the following scripts:

```
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1
mesh surface in sdl1t
```

To prevent creating skewed mesh, `scheme hole rad_intervals 1` is applied. This routine repeats for the surfaces `sdl2t, sdl3t, sdl4t, sdl5t`, and `sdl6t`.

The vertical curves of the volume are divided by 20 ft then 25 element levels are created because the thickness of the overburden layer is 500 ft. Then, the volumes are meshed entirely with the meshed horizontal sections and vertical curves. The meshed inner and six onion skins volumes are defined as `Element Blocks 180500, 180501, 180502, 180503, 180504, 180505`, and `180506`, respectively, as defined in Section 3.5.1.

The meshed block is saved into the storage through **save_wo_ns_ss.jou** (File 14) (replacing 001 by 018). The Cubit output (**bc018_500.cub**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\`, and the Genesis file (**bc018_500.g0**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\g0\`. The abstract file will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\abs\`. The onion skin volume (**bc018_500_skn.cub**) will be saved into the directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\`. The onion skin volume will be used for punching the dome slice volume in the overburden layer to make the hole for BC-18 column.

File 49: vtx_0500.jou

```
# Top elevation       : {TELE=       0      } ft
# Bottom elevation    : {BELE=       -500   } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume    : {VDL1=TNSB+2}
# created 2nd drawdown skin volume    : {VDL2=TNSB+3}
# created 3rd drawdown skin volume    : {VDL3=TNSB+4}
# created 4th drawdown skin volume    : {VDL4=TNSB+5}
# created 5th drawdown skin volume    : {VDL5=TNSB+6}
# created 6th drawdown skin volume    : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  355.85         -14.53         0
create vertex  354.96         -4.09          0
create vertex  349.32         4.84           0
.
.                                                  36 lines   cavern perimeter
.
create vertex  356.58         -47.64         0
create vertex  357.22         -35.93         0
create vertex  356.48         -24.94         0
### Drawdown 1 ---------------------------------
create vertex  360.13         -14.16         0
create vertex  359.17         -2.96          0
create vertex  353.13         6.62           0
.
.                                                             1st skin perimeter
.
create vertex  360.91         -49.67         0
create vertex  361.60         -37.11         0
create vertex  360.80         -25.32         0
### Drawdown 2 ---------------------------------
create vertex  364.71         -13.76         0
create vertex  363.69         -1.75          0
create vertex  357.21         8.52           0
.
.                                                             2nd skin perimeter
.
create vertex  365.56         -51.84         0
create vertex  366.30         -38.37         0
create vertex  365.44         -25.73         0
### Drawdown 3 ---------------------------------
create vertex  369.63         -13.33         0
create vertex  368.54         -0.46          0
create vertex  361.59         10.56          0
.
.                                                             3rd skin perimeter   Top
.
create vertex  370.54         -54.17         0
create vertex  371.33         -39.73         0
create vertex  370.41         -26.17         0
### Drawdown 4 ---------------------------------
create vertex  374.91         -12.87         0
create vertex  373.73         0.93           0
create vertex  366.28         12.75          0
.
.                                                             4th skin perimeter
.
create vertex  375.88         -56.66         0
create vertex  376.73         -41.18         0
create vertex  375.74         -26.64         0
### Drawdown 5 ---------------------------------
create vertex  380.57         -12.38         0
create vertex  379.31         2.43           0
create vertex  371.31         15.10          0
.
.                                                             5th skin perimeter
.
create vertex  381.61         -59.34         0
create vertex  382.52         -42.73         0
create vertex  381.46         -27.14         0
### Drawdown 6 ---------------------------------
create vertex  386.64         -11.85         0
create vertex  385.28         4.03           0
create vertex  376.71         17.61          0
.
.                                                             6th skin perimeter
.
create vertex  387.75         -62.21         0
create vertex  388.73         -44.40         0
create vertex  387.59         -27.68         0

(To be continued)
```

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  355.85         -14.53          -500
create vertex  354.96         -4.09           -500
create vertex  349.32         4.84            -500
.
.
.
create vertex  356.58         -47.64          -500
create vertex  357.22         -35.93          -500
create vertex  356.48         -24.94          -500
### Drawdown 1 -----------------------------------
create vertex  360.13         -14.16          -500
create vertex  359.17         -2.96           -500
create vertex  353.13         6.62            -500
.
.
.
create vertex  360.91         -49.67          -500
create vertex  361.60         -37.11          -500
create vertex  360.80         -25.32          -500
### Drawdown 2 -----------------------------------
create vertex  364.71         -13.76          -500
create vertex  363.69         -1.75           -500
create vertex  357.21         8.52            -500
.
.
.
create vertex  365.56         -51.84          -500
create vertex  366.30         -38.37          -500
create vertex  365.44         -25.73          -500
### Drawdown 3 -----------------------------------
create vertex  369.63         -13.33          -500
create vertex  368.54         -0.46           -500
create vertex  361.59         10.56           -500
.
.
.
create vertex  370.54         -54.17          -500
create vertex  371.33         -39.73          -500
create vertex  370.41         -26.17          -500
### Drawdown 4 -----------------------------------
create vertex  374.91         -12.87          -500
create vertex  373.73         0.93            -500
create vertex  366.28         12.75           -500
.
.
.
create vertex  375.88         -56.66          -500
create vertex  376.73         -41.18          -500
create vertex  375.74         -26.64          -500
### Drawdown 5 -----------------------------------
create vertex  380.57         -12.38          -500
create vertex  379.31         2.43            -500
create vertex  371.31         15.10           -500
.
.
.
create vertex  381.61         -59.34          -500
create vertex  382.52         -42.73          -500
create vertex  381.46         -27.14          -500
### Drawdown 6 -----------------------------------
create vertex  386.64         -11.85          -500
create vertex  385.28         4.03            -500
create vertex  376.71         17.61           -500
.
.
.
create vertex  387.75         -62.21          -500
create vertex  388.73         -44.40          -500
create vertex  387.59         -27.68          -500
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Bottom

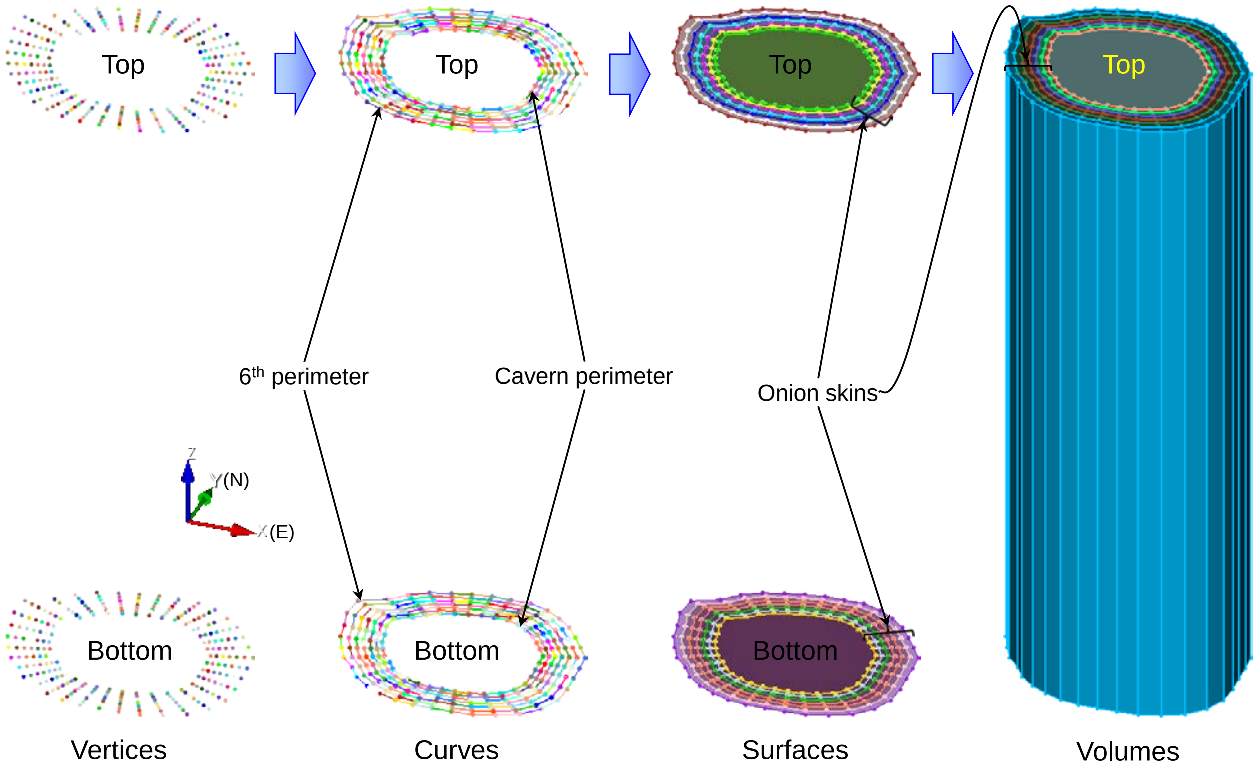


Figure 52: Vertices, curves, surfaces, and volumes of BC-18 column in overburden layer

File 50: create_vol.jou

```
Logging Errors on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\err\bc018_"//tostring(-
BELE)//".err")}
Set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\log\bc018_"//tostring(-
BELE)//".log")}

(To be continued)
```

```
# Create Curve =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) ------------------
create curve vertex {TVTX0=VI0*NVTX+1} {TVTX0+1}
create curve vertex {TVTX0+1  } {TVTX0+2     }
create curve vertex {TVTX0+2  } {TVTX0+3     }
.
.                                                     36 lines    cavern perimeter
.
create curve vertex {TVTX0+33 } {TVTX0+34    }
create curve vertex {TVTX0+34 } {TVTX0+35    }
create curve vertex {TVTX0+35 } {TVTX0       }
### Drawdown 1 ---------------------------------
create curve vertex {TVTX1=VI1*NVTX+1} {TVTX1+1}
create curve vertex {TVTX1+1  } {TVTX1+2     }
create curve vertex {TVTX1+2  } {TVTX1+3     }
.
.                                                                1st skin perimeter
.
create curve vertex {TVTX1+33 } {TVTX1+34    }
create curve vertex {TVTX1+34 } {TVTX1+35    }
create curve vertex {TVTX1+35 } {TVTX1       }
### Drawdown 2 ---------------------------------
create curve vertex {TVTX2=VI2*NVTX+1} {TVTX2+1}
create curve vertex {TVTX2+1  } {TVTX2+2     }
create curve vertex {TVTX2+2  } {TVTX2+3     }
.
.                                                                2nd skin perimeter
.
create curve vertex {TVTX2+33 } {TVTX2+34    }
create curve vertex {TVTX2+34 } {TVTX2+35    }
create curve vertex {TVTX2+35 } {TVTX2       }
### Drawdown 3 ---------------------------------
create curve vertex {TVTX3=VI3*NVTX+1} {TVTX3+1}
create curve vertex {TVTX3+1  } {TVTX3+2     }
create curve vertex {TVTX3+2  } {TVTX3+3     }
.
.                                                                3rd skin perimeter   Top
.
create curve vertex {TVTX3+33 } {TVTX3+34    }
create curve vertex {TVTX3+34 } {TVTX3+35    }
create curve vertex {TVTX3+35 } {TVTX3       }
### Drawdown 4 ---------------------------------
create curve vertex {TVTX4=VI4*NVTX+1} {TVTX4+1}
create curve vertex {TVTX4+1  } {TVTX4+2     }
create curve vertex {TVTX4+2  } {TVTX4+3     }
.
.                                                                4th skin perimeter
.
create curve vertex {TVTX4+33 } {TVTX4+34    }
create curve vertex {TVTX4+34 } {TVTX4+35    }
create curve vertex {TVTX4+35 } {TVTX4       }
### Drawdown 5 ---------------------------------
create curve vertex {TVTX5=VI5*NVTX+1} {TVTX5+1}
create curve vertex {TVTX5+1  } {TVTX5+2     }
create curve vertex {TVTX5+2  } {TVTX5+3     }
.
.                                                                5th skin perimeter
.
create curve vertex {TVTX5+33 } {TVTX5+34    }
create curve vertex {TVTX5+34 } {TVTX5+35    }
create curve vertex {TVTX5+35 } {TVTX5       }
### Drawdown 6 ---------------------------------
create curve vertex {TVTX6=VI6*NVTX+1} {TVTX6+1}
create curve vertex {TVTX6+1  } {TVTX6+2     }
create curve vertex {TVTX6+2  } {TVTX6+3     }
.
.                                                                6th skin perimeter
.
create curve vertex {TVTX6+33 } {TVTX6+34    }
create curve vertex {TVTX6+34 } {TVTX6+35    }
create curve vertex {TVTX6+35 } {TVTX6       }

(To be continued)
```

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create curve vertex {BVTX0=(NVOL+VI0)*NVTX+1 } {BVTX0+1}
create curve vertex {BVTX0+1  } {BVTX0+2     }
create curve vertex {BVTX0+2  } {BVTX0+3     }
.
.                                                          36 lines   cavern perimeter
.
create curve vertex {BVTX0+33 } {BVTX0+34    }
create curve vertex {BVTX0+34 } {BVTX0+35    }
create curve vertex {BVTX0+35 } {BVTX0       }
### Drawdown 1 ---------------------------------
create curve vertex {BVTX1=(NVOL+VI1)*NVTX+1 } {BVTX1+1}
create curve vertex {BVTX1+1  } {BVTX1+2     }
create curve vertex {BVTX1+2  } {BVTX1+3     }
.
.                                                                     1st skin perimeter
.
create curve vertex {BVTX1+33 } {BVTX1+34    }
create curve vertex {BVTX1+34 } {BVTX1+35    }
create curve vertex {BVTX1+35 } {BVTX1       }
### Drawdown 2 ---------------------------------
create curve vertex {BVTX2=(NVOL+VI2)*NVTX+1 } {BVTX2+1}
create curve vertex {BVTX2+1  } {BVTX2+2     }
create curve vertex {BVTX2+2  } {BVTX2+3     }
.
.                                                                     2nd skin perimeter
.
create curve vertex {BVTX2+33 } {BVTX2+34    }
create curve vertex {BVTX2+34 } {BVTX2+35    }
create curve vertex {BVTX2+35 } {BVTX2       }
### Drawdown 3 ---------------------------------
create curve vertex {BVTX3=(NVOL+VI3)*NVTX+1 } {BVTX3+1}
create curve vertex {BVTX3+1  } {BVTX3+2     }
create curve vertex {BVTX3+2  } {BVTX3+3     }
.
.                                                                     3rd skin perimeter   Bottom
.
create curve vertex {BVTX3+33 } {BVTX3+34    }
create curve vertex {BVTX3+34 } {BVTX3+35    }
create curve vertex {BVTX3+35 } {BVTX3       }
### Drawdown 4 ---------------------------------
create curve vertex {BVTX4=(NVOL+VI4)*NVTX+1 } {BVTX4+1}
create curve vertex {BVTX4+1  } {BVTX4+2     }
create curve vertex {BVTX4+2  } {BVTX4+3     }
.
.                                                                     4th skin perimeter
.
create curve vertex {BVTX4+33 } {BVTX4+34    }
create curve vertex {BVTX4+34 } {BVTX4+35    }
create curve vertex {BVTX4+35 } {BVTX4       }
### Drawdown 6 ---------------------------------
create curve vertex {BVTX5=(NVOL+VI5)*NVTX+1 } {BVTX5+1}
create curve vertex {BVTX5+1  } {BVTX5+2     }
create curve vertex {BVTX5+2  } {BVTX5+3     }
.
.                                                                     5th skin perimeter
.
create curve vertex {BVTX5+33 } {BVTX5+34    }
create curve vertex {BVTX5+34 } {BVTX5+35    }
create curve vertex {BVTX5+35 } {BVTX5       }
### Drawdown 6 ---------------------------------
create curve vertex {BVTX6=(NVOL+VI6)*NVTX+1 } {BVTX6+1}
create curve vertex {BVTX6+1  } {BVTX6+2     }
create curve vertex {BVTX6+2  } {BVTX6+3     }
.
.                                                                     6th skin perimeter
.
create curve vertex {BVTX6+33 } {BVTX6+34    }
create curve vertex {BVTX6+34 } {BVTX6+35    }
create curve vertex {BVTX6+35 } {BVTX6       }

(To be continued)
```

```
# Create Surface ====================================================
Create surface curve   {TVTX0} to      {TVTX1-1}
Create surface curve   {TVTX1} to      {TVTX2-1}
Create surface curve   {TVTX2} to      {TVTX3-1}
Create surface curve   {TVTX3} to      {TVTX4-1}
Create surface curve   {TVTX4} to      {TVTX5-1}
Create surface curve   {TVTX5} to      {TVTX6-1}
Create surface curve   {TVTX6} to      {BVTX0-1}
Create surface curve   {BVTX0} to      {BVTX1-1}
Create surface curve   {BVTX1} to      {BVTX2-1}
Create surface curve   {BVTX2} to      {BVTX3-1}
Create surface curve   {BVTX3} to      {BVTX4-1}
Create surface curve   {BVTX4} to      {BVTX5-1}
Create surface curve   {BVTX5} to      {BVTX6-1}
Create surface curve   {BVTX6} to      {TNVTX}

# Create Volume =====================================================
### Drawdown 0 (Initial Cavern) -----------------
create volume loft surface {TSI0} {BSI0} \
match vertex {TVTX0    } {BVTX0       } \
match vertex {TVTX0+1  } {BVTX0+1     } \
match vertex {TVTX0+2  } {BVTX0+2     } \
.
.                                                     36 lines    cavern column volume
.
match vertex {TVTX0+33 } {BVTX0+33    } \
match vertex {TVTX0+34 } {BVTX0+34    } \
match vertex {TVTX0+35 } {BVTX0+35    }
### Drawdown 1 ---------------------------------
create volume loft surface {TSI1} {BSI1} \
match vertex {TVTX1    } {BVTX1       } \
match vertex {TVTX1+1  } {BVTX1+1     } \
match vertex {TVTX1+2  } {BVTX1+2     } \
.
.                                                                 1st skin column volume
.
match vertex {TVTX1+33 } {BVTX1+33    } \
match vertex {TVTX1+34 } {BVTX1+34    } \
match vertex {TVTX1+35 } {BVTX1+35    }
### Drawdown 2 ---------------------------------
create volume loft surface {TSI2} {BSI2} \
match vertex {TVTX2    } {BVTX2       } \
match vertex {TVTX2+1  } {BVTX2+1     } \
.
.                                                                 2nd skin column volume
.
match vertex {TVTX2+33 } {BVTX2+33    } \
match vertex {TVTX2+34 } {BVTX2+34    } \
match vertex {TVTX2+35 } {BVTX2+35    }

 (To be continued)
```

```
### Drawdown 3 ----------------------------------
create volume loft surface {TSI3      } {BSI3 } \
match vertex {TVTX3    } {BVTX3      } \
match vertex {TVTX3+1  } {BVTX3+1    } \
.
.
.
match vertex {TVTX3+33 } {BVTX3+33    } \
match vertex {TVTX3+34 } {BVTX3+34    } \
match vertex {TVTX3+35 } {BVTX3+35    }
### Drawdown 4 ----------------------------------
create volume loft surface {TSI4      } {BSI4 } \
match vertex {TVTX4    } {BVTX4      } \
match vertex {TVTX4+1  } {BVTX4+1    } \
.
.
.
match vertex {TVTX4+33 } {BVTX4+33    } \
match vertex {TVTX4+34 } {BVTX4+34    } \
match vertex {TVTX4+35 } {BVTX4+35    }
### Drawdown 5 ----------------------------------
create volume loft surface {TSI5      } {BSI5 } \
match vertex {TVTX5    } {BVTX5      } \
match vertex {TVTX5+1  } {BVTX5+1    } \
.
.
.
match vertex {TVTX5+33 } {BVTX5+33    } \
match vertex {TVTX5+34 } {BVTX5+34    } \
match vertex {TVTX5+35 } {BVTX5+35    }
### Drawdown 6 ----------------------------------
create volume loft surface {TSI6      } {BSI6 } \
match vertex {TVTX6    } {BVTX6      } \
match vertex {TVTX6+1  } {BVTX6+1    } \
.
.
.
match vertex {TVTX6+33 } {BVTX6+33    } \
match vertex {TVTX6+34 } {BVTX6+34    } \
match vertex {TVTX6+35 } {BVTX6+35    }

## Create onion skin volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~
webcut body {TNSB+VI6+1} tool body {TNSB+VI5+1}
webcut body {TNSB+VI5+1} tool body {TNSB+VI4+1}
webcut body {TNSB+VI4+1} tool body {TNSB+VI3+1}
webcut body {TNSB+VI3+1} tool body {TNSB+VI2+1}
webcut body {TNSB+VI2+1} tool body {TNSB+VI1+1}
webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}
#
delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}
### remove the vertices on the curves BEtween the top and bottom
simplify curve all except curve      {TVTX0} to {TNVTX}
merge all  # to remove unnecessary vertices
delete body 1 to {TNSB}
```

36 lines

3rd skin column volume

4th skin column volume

5th skin column volume

6th skin column volume

File 51: mesh_surface.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh =============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) ----------------
surface in sdl0t vertex {TVTX0} to {TVTX1-1} type side
surface in sdl0t interval 1
mesh surface in sdl0t
#### Smoothing -----------------------
surface in sdl0t smooth scheme cond
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t
### Drawdown 1 ---------------------------------
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl1t
### Drawdown 2 ---------------------------------
surface in sdl2t interval 1
surface in sdl2t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl2t
### Drawdown 3 ---------------------------------
surface in sdl3t interval 1
surface in sdl3t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl3t
### Drawdown 4 ---------------------------------
surface in sdl4t interval 1
surface in sdl4t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl4t
### Drawdown 5 ---------------------------------
surface in sdl5t interval 1
surface in sdl5t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl5t
### Drawdown 6 ---------------------------------
surface in sdl6t interval 1
surface in sdl6t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl6t

(To be continued)
```

```
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 -----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 2 -----------------------------------
curve in cdl2w interval {(TELE-BELE)/TL}
curve in cdl2w scheme equal
mesh curve in cdl2w
### Drawdown 3 -----------------------------------
curve in cdl3w interval {(TELE-BELE)/TL}
curve in cdl3w scheme equal
mesh curve in cdl3w
### Drawdown 4 -----------------------------------
curve in cdl4w interval {(TELE-BELE)/TL}
curve in cdl4w scheme equal
mesh curve in cdl4w
### Drawdown 5 -----------------------------------
curve in cdl5w interval {(TELE-BELE)/TL}
curve in cdl5w scheme equal
mesh curve in cdl5w
### Drawdown 6 -----------------------------------
curve in cdl6w interval {(TELE-BELE)/TL}
curve in cdl6w scheme equal
mesh curve in cdl6w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL6} interval 1
mesh volume {VDL0} to {VDL6}
# Define Blocks ==================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
```

File 52: define_group_6dd.jou

```
## Define group ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
group "tcurv" add curve in volume all with z_coord > {TELE-1}
group "bcurv" add curve in volume all with z_coord < {BELE+1}
group "tsurf" add surface in volume all with z_coord > {TELE-1}
group "bsurf" add surface in volume all with z_coord < {BELE+1}
group "msurf" add surface in volume all
group "msurf" remove surface in tsurf
group "msurf" remove surface in bsurf
### Drawdown 0 (Initial Cavern) -----------------
#### Curves on outside wall of the volume
group "cdl0w" add curve in volume {VDL0}
group "cdl0w" remove curve in tcurv
group "cdl0w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl0t" add surface in volume {VDL0}
group "sdl0t" remove surface in msurf
group "sdl0t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl0w" add surface in volume {VDL0}
group "sdl0w" remove surface in tsurf
group "sdl0w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl0b" add surface in volume {VDL0}
group "sdl0b" remove surface in msurf
group "sdl0b" remove surface in tsurf
### Drawdown 1 --------------------------------
#### Curves on outside wall of the volume
group "cdl1w" add curve in volume {VDL1}
group "cdl1w" remove curve in volume {VDL0}
group "cdl1w" remove curve in tcurv
group "cdl1w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl1t" add surface in volume {VDL1}
group "sdl1t" remove surface in msurf
group "sdl1t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl1w" add surface in volume {VDL1}
group "sdl1w" remove surface in volume {VDL0}
group "sdl1w" remove surface in tsurf
group "sdl1w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl1b" add surface in volume {VDL1}
group "sdl1b" remove surface in msurf
group "sdl1b" remove surface in tsurf
### Drawdown 2 --------------------------------
#### Curves on outside wall of the volume
group "cdl2w" add curve in volume {VDL2}
group "cdl2w" remove curve in volume {VDL1}
group "cdl2w" remove curve in tcurv
group "cdl2w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl2t" add surface in volume {VDL2}
group "sdl2t" remove surface in msurf
group "sdl2t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl2w" add surface in volume {VDL2}
group "sdl2w" remove surface in volume {VDL1}
group "sdl2w" remove surface in tsurf
group "sdl2w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl2b" add surface in volume {VDL2}
group "sdl2b" remove surface in msurf
group "sdl2b" remove surface in tsurf

(To be continued)
```

```
### Drawdown 4 --------------------------------
#### Curves on outside wall of the volume
group "cdl4w" add curve in volume {VDL4}
group "cdl4w" remove curve in volume {VDL3}
group "cdl4w" remove curve in tcurv
group "cdl4w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl4t" add surface in volume {VDL4}
group "sdl4t" remove surface in msurf
group "sdl4t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl4w" add surface in volume {VDL4}
group "sdl4w" remove surface in volume {VDL3}
group "sdl4w" remove surface in tsurf
group "sdl4w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl4b" add surface in volume {VDL4}
group "sdl4b" remove surface in msurf
group "sdl4b" remove surface in tsurf
### Drawdown 5 --------------------------------
#### Curves on outside wall of the volume
group "cdl5w" add curve in volume {VDL5}
group "cdl5w" remove curve in volume {VDL4}
group "cdl5w" remove curve in tcurv
group "cdl5w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl5t" add surface in volume {VDL5}
group "sdl5t" remove surface in msurf
group "sdl5t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl5w" add surface in volume {VDL5}
group "sdl5w" remove surface in volume {VDL4}
group "sdl5w" remove surface in tsurf
group "sdl5w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl5b" add surface in volume {VDL5}
group "sdl5b" remove surface in msurf
group "sdl5b" remove surface in tsurf
### Drawdown 6 --------------------------------
#### Curves on outside wall of the volume
group "cdl6w" add curve in volume {VDL6}
group "cdl6w" remove curve in volume {VDL5}
group "cdl6w" remove curve in tcurv
group "cdl6w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl6t" add surface in volume {VDL6}
group "sdl6t" remove surface in msurf
group "sdl6t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl6w" add surface in volume {VDL6}
group "sdl6w" remove surface in volume {VDL5}
group "sdl6w" remove surface in tsurf
group "sdl6w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl6b" add surface in volume {VDL6}
group "sdl6b" remove surface in msurf
group "sdl6b" remove surface in tsurf
### Skin for webcut = {skn=VDL6} ----------------
```

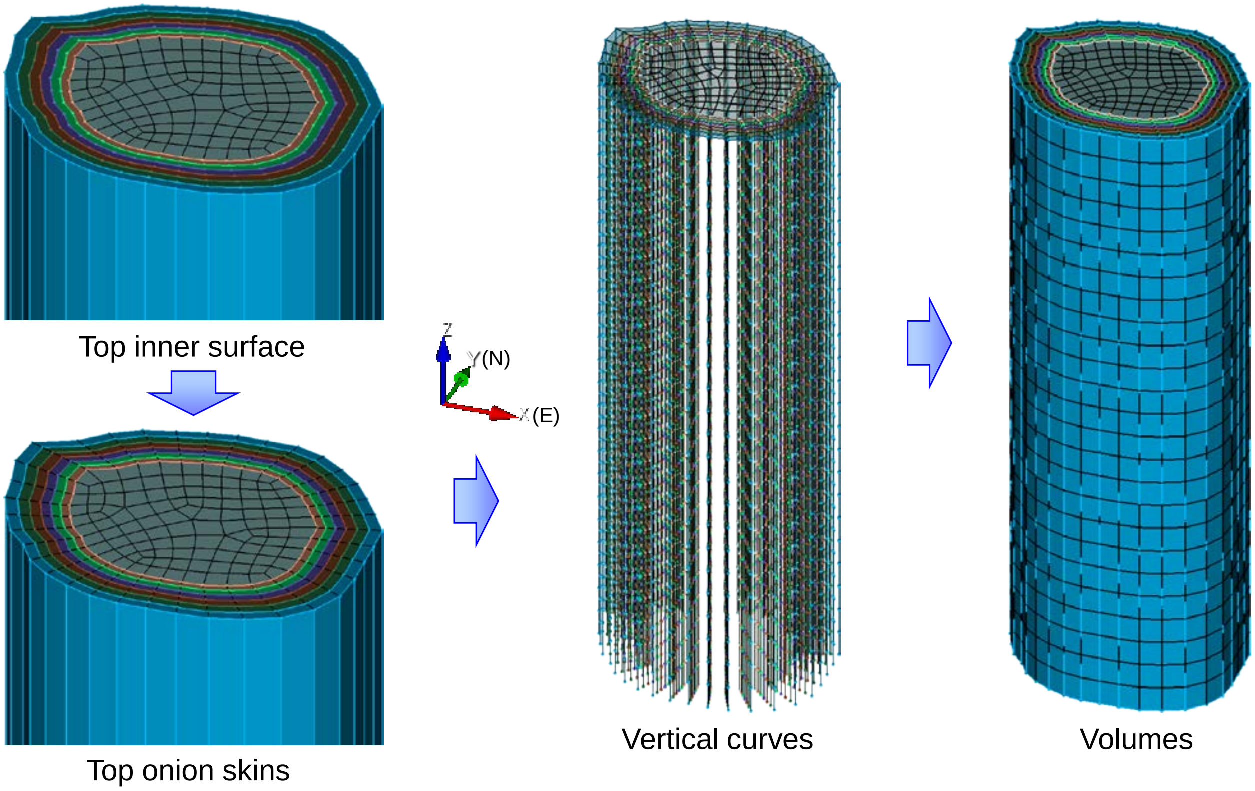


Figure 53: Steps to create mesh into BC-18 cavern column in overburden layer

6.4.4. Blocks in caprock and interbed layers

The blocks in caprock and interbed layers are constructed by using the Cubit journal file **`bot_0660_above.jou`** (File 4) and **`bot_0680_above.jou`** (File 5), respectively, like BC-1.

The command line of **`bot_0660.jou`** (File 49) in File 4 is the Cubit journal file to create the vertices for the BC-18 cavern column volumes in the caprock layer 160 ft thick. The elevations of the top and bottom of the block are -500 ft and -660 ft, respectively. The X- and Y- coordinates of the vertices are the same as those of the BC-18 cavern column block in the overburden layer because their horizontal cross-sections are the same. Figure 54 shows the steps to create the block. **`create_vol.jou`** (File 50) is used to create the block which consists of the inner and six skin volumes.

The block in the interbed layer 20 ft thick is created using **`bot_0680_above.jou`** in File 5 that is similar to **`bot_0660.jou`** (File 49). The elevations (Z-coordinates) of the top and bottom of the interbed block are -660 ft and -680 ft, respectively. Therefore, -500 ft and -660 ft in **`bot_0660.jou`** are replaced with -660 ft and -680 ft, respectively, in **`bot_0680_above.jou`**. The X- and Y- coordinates of the vertices are also the same as those of the block above. Figure 55 shows the steps to create the block in the interbed layers. **`create_vol.jou`** (File 50) also is used to create the block.

`mesh_above_wo_ss.jou` (File 54) is the Cubit journal file to mesh the volumes in the caprock layer. To create the mesh on the top surface of the volumes, the meshed volumes (**`bc018_500.cub`**) created in the previous section is imported. The volumes in the caprock layer and the imported volumes are merged. Then the surfaces on the bottom of imported volumes become the surfaces on the top of the volumes in the caprock layer.

The vertical curves of the volumes in the caprock layer 160 ft thick are divided by 20 ft, and then 8 element levels are created. The meshes on the top surfaces of the volumes are translated to the bottom surfaces of the volumes. The unnecessary volumes are deleted. The meshed inner and six onion skins volumes are defined as `Element Blocks 180660, 180661, 180662, 180663, 180664, 180665`, and `180666`, respectively, as defined in Section 3.5.1.

The vertical curves of the volumes in the interbed layer 20 ft thick are divided by 20 ft, and then one element levels are created. The meshes on the top surfaces of the volumes are translated to the bottom surfaces of the volumes. The unnecessary volumes are deleted. The meshed inner and six onion skins volumes are defined as `Element Blocks 180680, 180681, 180682, 180683, 180684, 180685`, and `180686`, respectively, as defined in Section 3.5.1.

To save the meshed volumes, **`save_wo_ns_ss.jou`** (File 14) is used.

File 53: vtx_0660.jou

```
# Top elevation       : {TELE=       -500    } ft
# Bottom elevation    : {BELE=       -660    } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume  : {VDL0=TNSB+1}
# created 1st drawdown skin volume    : {VDL1=TNSB+2}
# created 2nd drawdown skin volume    : {VDL2=TNSB+3}
# created 3rd drawdown skin volume    : {VDL3=TNSB+4}
# created 4th drawdown skin volume    : {VDL4=TNSB+5}
# created 5th drawdown skin volume    : {VDL5=TNSB+6}
# created 6th drawdown skin volume    : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  355.85         -14.53          -500
create vertex  354.96         -4.09           -500
create vertex  349.32         4.84            -500
.
.                                                        36 lines   cavern perimeter
.
create vertex  356.58         -47.64          -500
create vertex  357.22         -35.93          -500
create vertex  356.48         -24.94          -500
### Drawdown 1 ----------------------------------
create vertex  360.13         -14.16          -500
create vertex  359.17         -2.96           -500
create vertex  353.13         6.62            -500
.
.                                                                   1st skin perimeter
.
create vertex  360.91         -49.67          -500
create vertex  361.60         -37.11          -500
create vertex  360.80         -25.32          -500
### Drawdown 2 ----------------------------------
create vertex  364.71         -13.76          -500
create vertex  363.69         -1.75           -500
create vertex  357.21         8.52            -500
.
.                                                                   2nd skin perimeter
.
create vertex  365.56         -51.84          -500
create vertex  366.30         -38.37          -500
create vertex  365.44         -25.73          -500
### Drawdown 3 ----------------------------------
create vertex  369.63         -13.33          -500
create vertex  368.54         -0.46           -500
create vertex  361.59         10.56           -500
.
.                                                                   3rd skin perimeter   Top
.
create vertex  370.54         -54.17          -500
create vertex  371.33         -39.73          -500
create vertex  370.41         -26.17          -500
### Drawdown 4 ----------------------------------
create vertex  374.91         -12.87          -500
create vertex  373.73         0.93            -500
create vertex  366.28         12.75           -500
.
.                                                                   4th skin perimeter
.
create vertex  375.88         -56.66          -500
create vertex  376.73         -41.18          -500
create vertex  375.74         -26.64          -500
### Drawdown 5 ----------------------------------
create vertex  380.57         -12.38          -500
create vertex  379.31         2.43            -500
create vertex  371.31         15.10           -500
.
.                                                                   5th skin perimeter
.
create vertex  381.61         -59.34          -500
create vertex  382.52         -42.73          -500
create vertex  381.46         -27.14          -500
### Drawdown 6 ----------------------------------
create vertex  386.64         -11.85          -500
create vertex  385.28         4.03            -500
create vertex  376.71         17.61           -500
.
.                                                                   6th skin perimeter
.
create vertex  387.75         -62.21          -500
create vertex  388.73         -44.40          -500
create vertex  387.59         -27.68          -500
```

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  355.85         -14.53          -660
create vertex  354.96         -4.09           -660
create vertex  349.32         4.84            -660
.
.
.
create vertex  356.58         -47.64          -660
create vertex  357.22         -35.93          -660
create vertex  356.48         -24.94          -660
```

36 lines

cavern perimeter

```
### Drawdown 1 ----------------------------------
create vertex  360.13         -14.16          -660
create vertex  359.17         -2.96           -660
create vertex  353.13         6.62            -660
.
.
.
create vertex  360.91         -49.67          -660
create vertex  361.60         -37.11          -660
create vertex  360.80         -25.32          -660
```

1st skin perimeter

```
### Drawdown 2 ----------------------------------
create vertex  364.71         -13.76          -660
create vertex  363.69         -1.75           -660
create vertex  357.21         8.52            -660
.
.
.
create vertex  365.56         -51.84          -660
create vertex  366.30         -38.37          -660
create vertex  365.44         -25.73          -660
```

2nd skin perimeter

```
### Drawdown 3 ----------------------------------
create vertex  369.63         -13.33          -660
create vertex  368.54         -0.46           -660
create vertex  361.59         10.56           -660
.
.
.
create vertex  370.54         -54.17          -660
create vertex  371.33         -39.73          -660
create vertex  370.41         -26.17          -660
```

3rd skin perimeter

Bottom

```
### Drawdown 4 ----------------------------------
create vertex  374.91         -12.87          -660
create vertex  373.73         0.93            -660
create vertex  366.28         12.75           -660
.
.
.
create vertex  375.88         -56.66          -660
create vertex  376.73         -41.18          -660
create vertex  375.74         -26.64          -660
```

4th skin perimeter

```
### Drawdown 5 ----------------------------------
create vertex  380.57         -12.38          -660
create vertex  379.31         2.43            -660
create vertex  371.31         15.10           -660
.
.
.
create vertex  381.61         -59.34          -660
create vertex  382.52         -42.73          -660
create vertex  381.46         -27.14          -660
```

5th skin perimeter

```
### Drawdown 6 ----------------------------------
create vertex  386.64         -11.85          -660
create vertex  385.28         4.03            -660
create vertex  376.71         17.61           -660
.
.
.
create vertex  387.75         -62.21          -660
create vertex  388.73         -44.40          -660
create vertex  387.59         -27.68          -660
```

6th skin perimeter

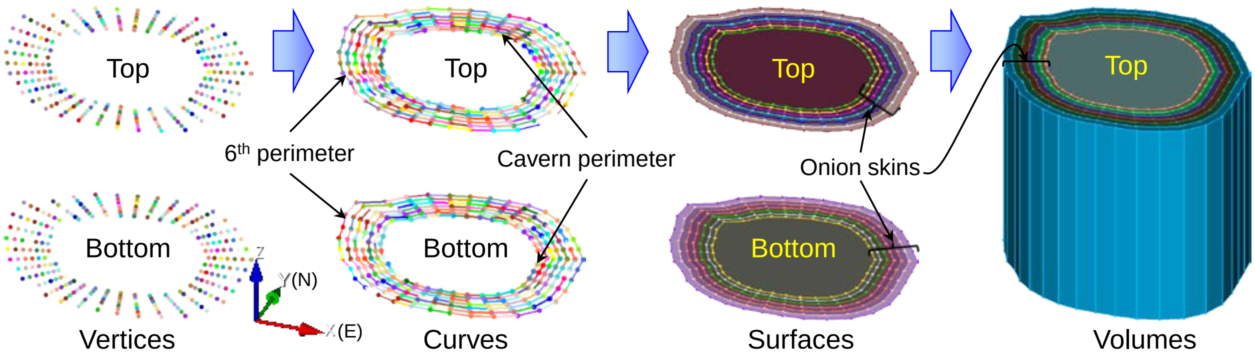


Figure 54: Vertices, curves, surfaces, and volumes of BC-18 column in caprock layer

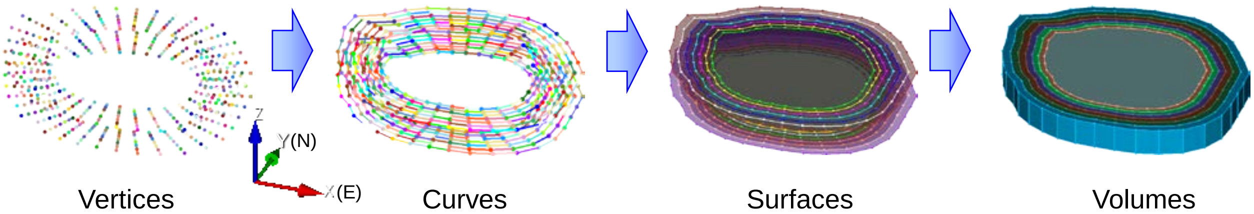


Figure 55: Vertices, curves, surfaces, and volumes of BC-18 column in interbed layer

File 54: mesh_above_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 2 ----------------------------------
curve in cdl2w interval {(TELE-BELE)/TL}
curve in cdl2w scheme equal
mesh curve in cdl2w
### Drawdown 3 ----------------------------------
curve in cdl3w interval {(TELE-BELE)/TL}
curve in cdl3w scheme equal
mesh curve in cdl3w
### Drawdown 4 ----------------------------------
curve in cdl4w interval {(TELE-BELE)/TL}
curve in cdl4w scheme equal
mesh curve in cdl4w
### Drawdown 5 ----------------------------------
curve in cdl5w interval {(TELE-BELE)/TL}
curve in cdl5w scheme equal
mesh curve in cdl5w
### Drawdown 6 ----------------------------------
curve in cdl6w interval {(TELE-BELE)/TL}
curve in cdl6w scheme equal
mesh curve in cdl6w

(To be continued)
```

```
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ---------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
### Drawdown 2 ---------------------------------
volume {VDL2} scheme Sweep  source surface in sdl2t target surface in sdl2b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL2}
### Drawdown 3 ---------------------------------
volume {VDL3} scheme Sweep  source surface in sdl3t target surface in sdl3b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL3}
### Drawdown 4 ---------------------------------
volume {VDL4} scheme Sweep  source surface in sdl4t target surface in sdl4b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL4}
### Drawdown 5 ---------------------------------
volume {VDL5} scheme Sweep  source surface in sdl5t target surface in sdl5b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL5}
### Drawdown 6 ---------------------------------
volume {VDL6} scheme Sweep  source surface in sdl6t target surface in sdl6b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL6}
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
```

6.4.5. Upper salt block

The upper salt block is constructed with **`bot_2140_above.jou`** (File 55).

The command line of **`vtx_2140.jou`** (File 56) in File 55 is the Cubit journal file to create the vertices for the BC-18 cavern column block between the interbed layer and cavern roof. The elevations of the top and bottom of the block are -680 ft and -2140 ft, respectively. The X- and Y- coordinates on the top are not the same as those on the bottom because the cavern column leans to the west to be parallel to the dome edge. To create the cavern column volumes, **`create_vol.jou`** (File 50) is used. In the same manner as the previous section, the cavern column volumes are created as shown Figure 56.

To mesh the block, the command line of **`mesh_above_wo_ss.jou`** (File 54) in File 55 is used as described in the previous section. Figure 57 shows the steps to create the mesh into the upper salt block. As the first step, the block in the interbed layer is imported right above the upper salt block, and the bottom surfaces of the interbed block and the top surfaces of the upper salt block are merged to transfer the mesh. As the next step, the vertical curves of the volumes in the upper salt block 1460 ft height are divided by 20 ft, and then 73 intervals are created, and then the volumes in the upper salt block are meshed entirely. As the third step, the imported volumes are deleted. As the last step, meshed inner and six skin volumes are defined as `Element Blocks 182140, 182141, 182142, 182143, 182144, 182145`, and `182146`, respectively.

The meshed upper salt block is saved through the command scripts in **save_wo_ns_ss.jou** (File 14) (replacing 001 with 018).

File 55: bot_2140_above.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2140.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_above_wo_ss.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ns_ss.jou")}
#
exit
```

File 56: vtx_2140.jou

```
# Top elevation       : {TELE=       -680    } ft
# Bottom elevation    : {BELE=       -2140   } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices         : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes          : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
# created 2nd drawdown skin volume     : {VDL2=TNSB+3}
# created 3rd drawdown skin volume     : {VDL3=TNSB+4}
# created 4th drawdown skin volume     : {VDL4=TNSB+5}
# created 5th drawdown skin volume     : {VDL5=TNSB+6}
# created 6th drawdown skin volume     : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  355.85         -14.53         -680
create vertex  354.96         -4.09          -680
create vertex  349.32         4.84           -680
.
.
.
create vertex  356.58         -47.64         -680
create vertex  357.22         -35.93         -680
create vertex  356.48         -24.94         -680
### Drawdown 1 ----------------------------------
create vertex  360.13         -14.16         -680
create vertex  359.17         -2.96          -680
create vertex  353.13         6.62           -680
.
.
.
create vertex  360.91         -49.67         -680
create vertex  361.60         -37.11         -680
create vertex  360.80         -25.32         -680
### Drawdown 2 ----------------------------------
create vertex  364.71         -13.76         -680
create vertex  363.69         -1.75          -680
create vertex  357.21         8.52           -680
.
.
.
create vertex  365.56         -51.84         -680
create vertex  366.30         -38.37         -680
create vertex  365.44         -25.73         -680
### Drawdown 3 ----------------------------------
create vertex  369.63         -13.33         -680
create vertex  368.54         -0.46          -680
create vertex  361.59         10.56          -680
.
.
.
create vertex  370.54         -54.17         -680
create vertex  371.33         -39.73         -680
create vertex  370.41         -26.17         -680
### Drawdown 4 ----------------------------------
create vertex  374.91         -12.87         -680
create vertex  373.73         0.93           -680
create vertex  366.28         12.75          -680
.
.
.
create vertex  375.88         -56.66         -680
create vertex  376.73         -41.18         -680
create vertex  375.74         -26.64         -680
### Drawdown 5 ----------------------------------
create vertex  380.57         -12.38         -680
create vertex  379.31         2.43           -680
create vertex  371.31         15.10          -680
.
.
.
create vertex  381.61         -59.34         -680
create vertex  382.52         -42.73         -680
create vertex  381.46         -27.14         -680
### Drawdown 6 ----------------------------------
create vertex  386.64         -11.85         -680
create vertex  385.28         4.03           -680
create vertex  376.71         17.61          -680
.
.
.
create vertex  387.75         -62.21         -680
create vertex  388.73         -44.40         -680
create vertex  387.59         -27.68         -680
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

Top

4th skin perimeter

5th skin perimeter

6th skin perimeter

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  658.68         47.07          -2140
create vertex  657.79         57.51          -2140
create vertex  652.16         66.45          -2140
.
.
.
create vertex  659.42         13.96          -2140
create vertex  660.06         25.67          -2140
create vertex  659.31         36.66          -2140
### Drawdown 1 ----------------------------------
create vertex  662.96         47.45          -2140
create vertex  662.01         58.64          -2140
create vertex  655.96         68.22          -2140
.
.
.
create vertex  663.75         11.94          -2140
create vertex  664.44         24.50          -2140
create vertex  663.64         36.28          -2140
### Drawdown 2 ----------------------------------
create vertex  667.55         47.84          -2140
create vertex  666.53         59.85          -2140
create vertex  660.05         70.12          -2140
.
.
.
create vertex  668.39         9.77           -2140
create vertex  669.13         23.23          -2140
create vertex  668.28         35.87          -2140
### Drawdown 3 ----------------------------------
create vertex  672.47         48.27          -2140
create vertex  671.37         61.15          -2140
create vertex  664.42         72.17          -2140
.
.
.
create vertex  673.37         7.44           -2140
create vertex  674.17         21.88          -2140
create vertex  673.25         35.44          -2140
### Drawdown 4 ----------------------------------
create vertex  677.75         48.73          -2140
create vertex  676.57         62.54          -2140
create vertex  669.12         74.35          -2140
.
.
.
create vertex  678.71         4.94           -2140
create vertex  679.57         20.43          -2140
create vertex  678.58         34.97          -2140
### Drawdown 5 ----------------------------------
create vertex  683.40         49.23          -2140
create vertex  682.14         64.03          -2140
create vertex  674.15         76.70          -2140
.
.
.
create vertex  684.44         2.26           -2140
create vertex  685.35         18.87          -2140
create vertex  684.30         34.46          -2140
### Drawdown 6 ----------------------------------
create vertex  689.47         49.75          -2140
create vertex  688.12         65.63          -2140
create vertex  679.55         79.22          -2140
.
.
.
create vertex  690.58         -0.61          -2140
create vertex  691.56         17.20          -2140
create vertex  690.43         33.92          -2140
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Bottom

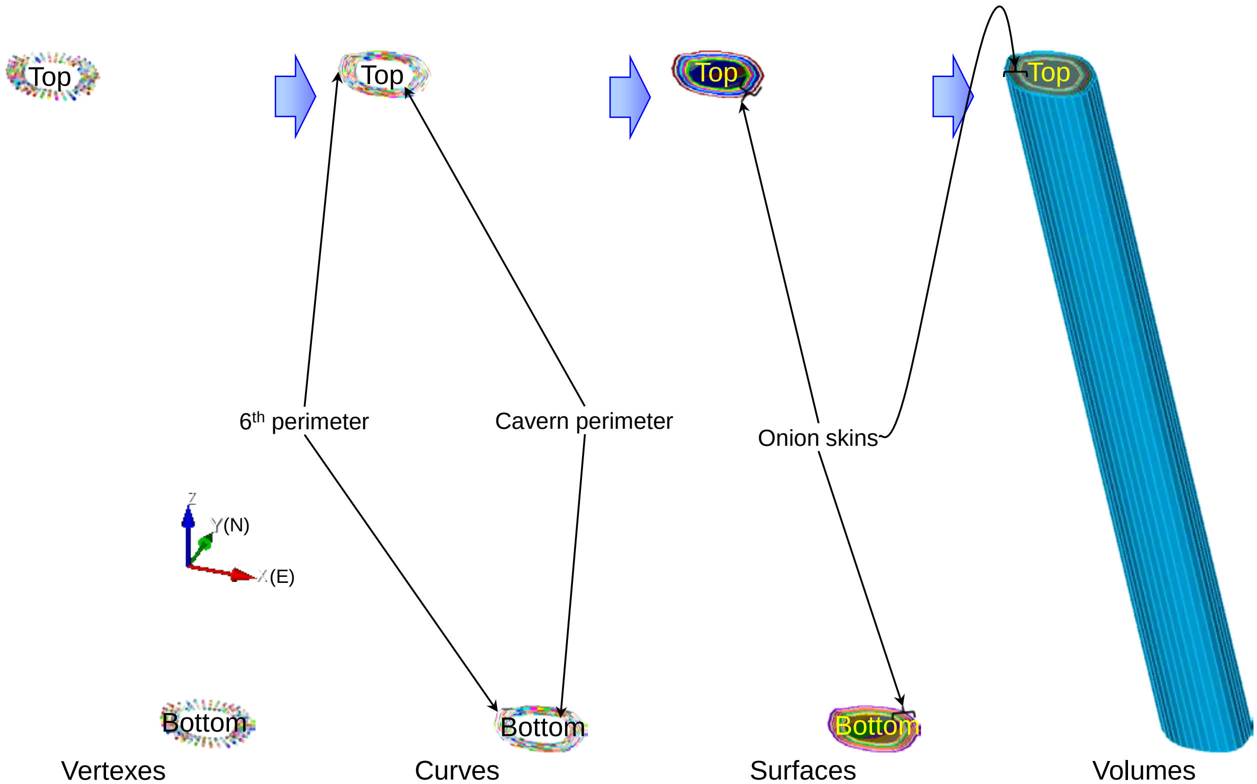


Figure 56: Vertices, curves, surfaces, and volumes of BC-18 column between interbed and roof

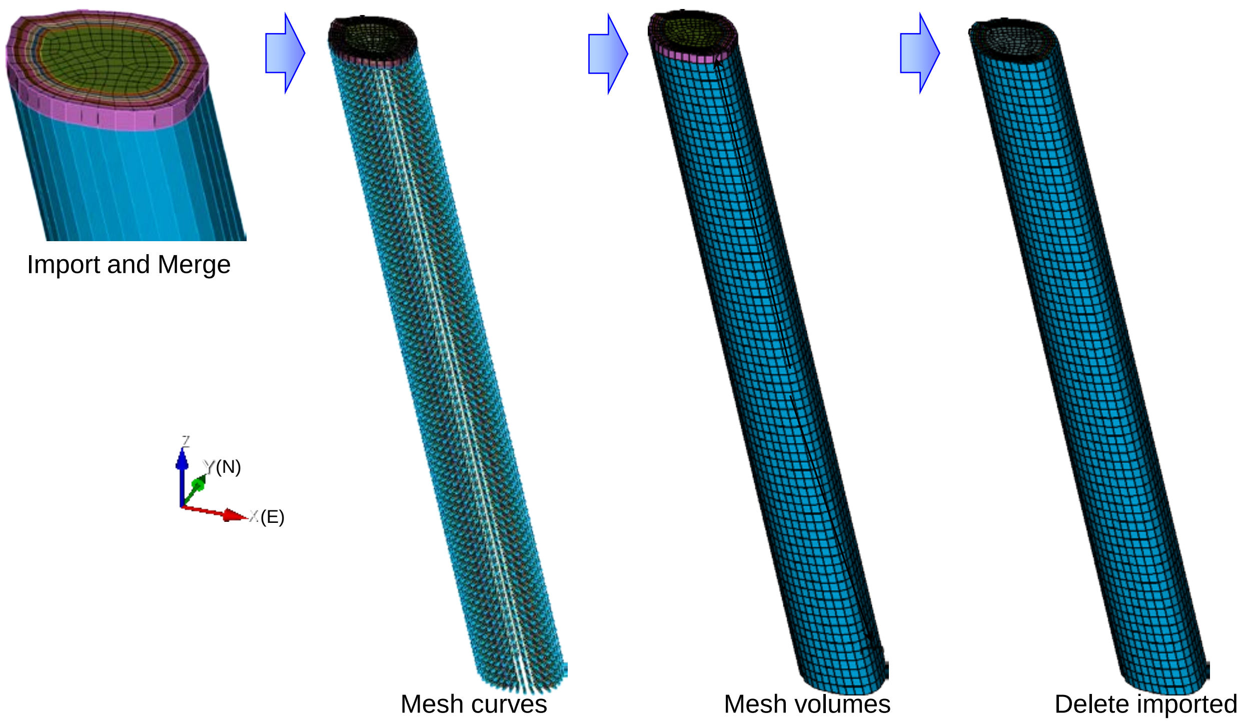


Figure 57: Steps to mesh the upper salt block over the cavern roof block of BC-18

6.4.6. Roof block

The roof block is constructed by using **`bot_2160_roof.jou`** (File 57).

The command line of **`vtx_2160.jou`** (File 58) in File 57 is the Cubit journal file to create the vertices for the BC-18 cavern roof. The elevations of the top and bottom of the roof block are -2140 ft and -2160 ft, respectively. The cavern roof volumes are created using **`create_vol.jou`** (File 50) as shown Figure 58.

To create the mesh in the volumes, **`mesh_roof.jou`** (File 59) is used. Figure 59 shows the steps to create the mesh into the cavern roof. As the first step, the upper salt block is imported on the cavern roof block, and the bottom surfaces of the upper salt block and the top surfaces of the roof block are merged to transfer the mesh. As the next step, the vertical curves on the roof block are meshed with one interval because the thickness of the roof block is 20 ft, and then the volumes in the roof block are meshed entirely. As the third step, the imported upper salt block is deleted. As the last step, The meshed inner and six skin volumes are defined as `Element Blocks 182160, 182161, 182162, 182163, 182164, 182165`, and `182166`, respectively. The side sets of the bottom surfaces of the blocks are defined as `Sidesets 182160, 182161, 182162, 182163, 182164`, and `182165`, respectively, on the bottom of the roof blocks as shown Figure 60.

The side sets represent the ceiling of the cavern. `Sidesets 182160` is the ceiling of the original cavern, `Sidesets 182161` is the ceiling of the cavern after the first drawdown leach. Thus, the bottom surfaces of `Element Blocks 182160` and `182161` are defined as `Sideset 182161`. In the same manner, `Sideset 182165` is the ceiling of the cavern after the fifth drawdown leaches. Thus, the bottom surfaces of the `Element Blocks 182160, 182161, 182162, 182163, 182164`, and `182165` are defined as `Sideset 182165`. The sixth `Element Block 182166` is considered like one onion skin of the Non-SPR cavern to check the analysis results at the wall, roof, and floor of the cavern. The inner and six skin blocks will be combined into one roof block in the GJOIN step.

The meshed roof block is saved through the command scripts in **`save.jou`** (File 21) (replacing 001 with 018) used for the overburden layer.

File 57: bot_2160_roof.jou

```
# Setup environment  ==============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ===================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2160.jou")}
# Create Curve ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_roof.jou")}
# Save ============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 58: vtx_2160.jou

```
# Top elevation       : {TELE=       -2140  } ft
# Bottom elevation     : {BELE=       -2160  } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume    : {VDL1=TNSB+2}
# created 2nd drawdown skin volume    : {VDL2=TNSB+3}
# created 3rd drawdown skin volume    : {VDL3=TNSB+4}
# created 4th drawdown skin volume    : {VDL4=TNSB+5}
# created 5th drawdown skin volume    : {VDL5=TNSB+6}
# created 6th drawdown skin volume    : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  658.68         47.07          -2140
create vertex  657.79         57.51          -2140
create vertex  652.16         66.45          -2140
.
.                                                     36 lines   cavern perimeter
.
create vertex  659.42         13.96          -2140
create vertex  660.06         25.67          -2140
create vertex  659.31         36.66          -2140
### Drawdown 1 ----------------------------------
create vertex  662.96         47.45          -2140
create vertex  662.01         58.64          -2140
create vertex  655.96         68.22          -2140
.
.                                                                1st skin perimeter
.
create vertex  663.75         11.94          -2140
create vertex  664.44         24.50          -2140
create vertex  663.64         36.28          -2140
### Drawdown 2 ----------------------------------
create vertex  667.55         47.84          -2140
create vertex  666.53         59.85          -2140
create vertex  660.05         70.12          -2140
.
.                                                                2nd skin perimeter
.
create vertex  668.39         9.77           -2140
create vertex  669.13         23.23          -2140
create vertex  668.28         35.87          -2140
### Drawdown 3 ----------------------------------
create vertex  672.47         48.27          -2140
create vertex  671.37         61.15          -2140
create vertex  664.42         72.17          -2140
.
.                                                                3rd skin perimeter   Top
.
create vertex  673.37         7.44           -2140
create vertex  674.17         21.88          -2140
create vertex  673.25         35.44          -2140
### Drawdown 4 ----------------------------------
create vertex  677.75         48.73          -2140
create vertex  676.57         62.54          -2140
create vertex  669.12         74.35          -2140
.
.                                                                4th skin perimeter
.
create vertex  678.71         4.94           -2140
create vertex  679.57         20.43          -2140
create vertex  678.58         34.97          -2140
### Drawdown 5 ----------------------------------
create vertex  683.40         49.23          -2140
create vertex  682.14         64.03          -2140
create vertex  674.15         76.70          -2140
.
.                                                                5th skin perimeter
.
create vertex  684.44         2.26           -2140
create vertex  685.35         18.87          -2140
create vertex  684.30         34.46          -2140
### Drawdown 6 ----------------------------------
create vertex  689.47         49.75          -2140
create vertex  688.12         65.63          -2140
create vertex  679.55         79.22          -2140
.
.                                                                6th skin perimeter
.
create vertex  690.58         -0.61          -2140
create vertex  691.56         17.20          -2140
create vertex  690.43         33.92          -2140

(To be continued)
```

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  658.68         47.07          -2160
create vertex  657.79         57.51          -2160
create vertex  652.16         66.45          -2160
.
.
.
create vertex  659.42         13.96          -2160
create vertex  660.06         25.67          -2160
create vertex  659.31         36.66          -2160
### Drawdown 1 ----------------------------------
create vertex  662.96         47.45          -2160
create vertex  662.01         58.64          -2160
create vertex  655.96         68.22          -2160
.
.
.
create vertex  663.75         11.94          -2160
create vertex  664.44         24.50          -2160
create vertex  663.64         36.28          -2160
### Drawdown 2 ----------------------------------
create vertex  667.55         47.84          -2160
create vertex  666.53         59.85          -2160
create vertex  660.05         70.12          -2160
.
.
.
create vertex  668.39         9.77           -2160
create vertex  669.13         23.23          -2160
create vertex  668.28         35.87          -2160
### Drawdown 3 ----------------------------------
create vertex  672.47         48.27          -2160
create vertex  671.37         61.15          -2160
create vertex  664.42         72.17          -2160
.
.
.
create vertex  673.37         7.44           -2160
create vertex  674.17         21.88          -2160
create vertex  673.25         35.44          -2160
### Drawdown 4 ----------------------------------
create vertex  677.75         48.73          -2160
create vertex  676.57         62.54          -2160
create vertex  669.12         74.35          -2160
.
.
.
create vertex  678.71         4.94           -2160
create vertex  679.57         20.43          -2160
create vertex  678.58         34.97          -2160
### Drawdown 5 ----------------------------------
create vertex  683.40         49.23          -2160
create vertex  682.14         64.03          -2160
create vertex  674.15         76.70          -2160
.
.
.
create vertex  684.44         2.26           -2160
create vertex  685.35         18.87          -2160
create vertex  684.30         34.46          -2160
### Drawdown 6 ----------------------------------
create vertex  689.47         49.75          -2160
create vertex  688.12         65.63          -2160
create vertex  679.55         79.22          -2160
.
.
.
create vertex  690.58         -0.61          -2160
create vertex  691.56         17.20          -2160
create vertex  690.43         33.92          -2160
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

Bottom

4th skin perimeter

5th skin perimeter

6th skin perimeter

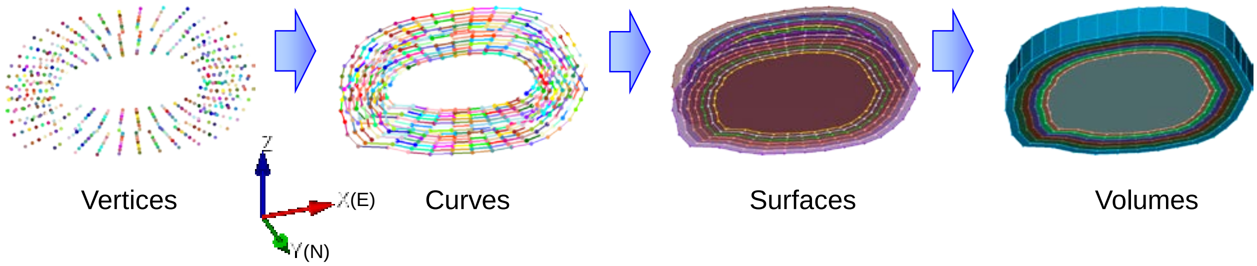


Figure 58: Vertices, curves, surfaces, and volumes of BC-18 cavern roof block

File 59: mesh_roof.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 2 ---------------------------------
curve in cdl2w interval {(TELE-BELE)/TL}
curve in cdl2w scheme equal
mesh curve in cdl2w
### Drawdown 3 ---------------------------------
curve in cdl3w interval {(TELE-BELE)/TL}
curve in cdl3w scheme equal
mesh curve in cdl3w
### Drawdown 4 ---------------------------------
curve in cdl4w interval {(TELE-BELE)/TL}
curve in cdl4w scheme equal
mesh curve in cdl4w
### Drawdown 5 ---------------------------------
curve in cdl5w interval {(TELE-BELE)/TL}
curve in cdl5w scheme equal
mesh curve in cdl5w
### Drawdown 6 ---------------------------------
curve in cdl6w interval {(TELE-BELE)/TL}
curve in cdl6w scheme equal
mesh curve in cdl6w

(To be continued)
```

```
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL6} interval 1
mesh volume {VDL0} to {VDL6}
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
# Define Sideset ====================================================
### Drawdown 0 (Initial Cavern) -----------------
sideset {BID+VI0} surface in sdl0b wrt volume {VDL0}
### Drawdown 1 ----------------------------------
sideset {BID+VI1} surface in sdl1b wrt volume {VDL1}
sideset {BID+VI1} surface in sdl0b wrt volume {VDL0}
### Drawdown 2 ----------------------------------
sideset {BID+VI2} surface in sdl2b wrt volume {VDL2}
sideset {BID+VI2} surface in sdl1b wrt volume {VDL1}
sideset {BID+VI2} surface in sdl0b wrt volume {VDL0}
### Drawdown 3 ----------------------------------
sideset {BID+VI3} surface in sdl3b wrt volume {VDL3}
sideset {BID+VI3} surface in sdl2b wrt volume {VDL2}
sideset {BID+VI3} surface in sdl1b wrt volume {VDL1}
sideset {BID+VI3} surface in sdl0b wrt volume {VDL0}
### Drawdown 4 ----------------------------------
sideset {BID+VI4} surface in sdl4b wrt volume {VDL4}
sideset {BID+VI4} surface in sdl3b wrt volume {VDL3}
sideset {BID+VI4} surface in sdl2b wrt volume {VDL2}
sideset {BID+VI4} surface in sdl1b wrt volume {VDL1}
sideset {BID+VI4} surface in sdl0b wrt volume {VDL0}
### Drawdown 5 ----------------------------------
sideset {BID+VI5} surface in sdl5b wrt volume {VDL5}
sideset {BID+VI5} surface in sdl4b wrt volume {VDL4}
sideset {BID+VI5} surface in sdl3b wrt volume {VDL3}
sideset {BID+VI5} surface in sdl2b wrt volume {VDL2}
sideset {BID+VI5} surface in sdl1b wrt volume {VDL1}
sideset {BID+VI5} surface in sdl0b wrt volume {VDL0}
```

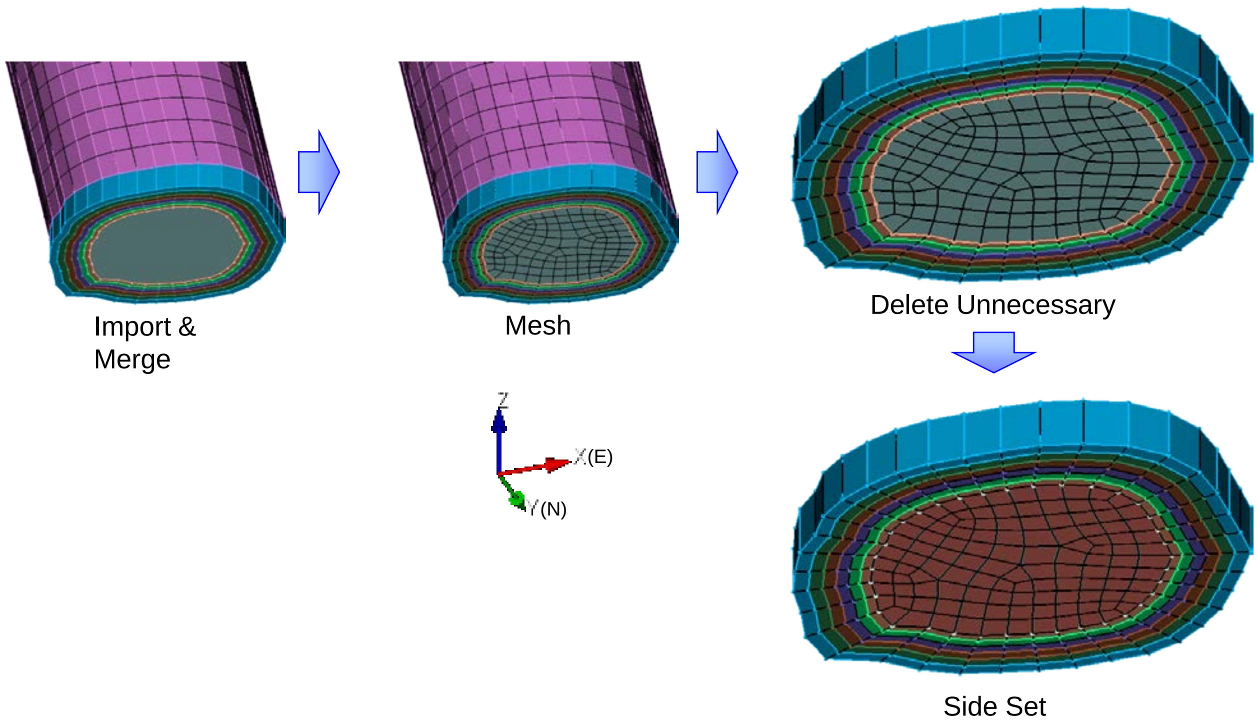


Figure 59: Steps to mesh the cavern roof block of BC-18

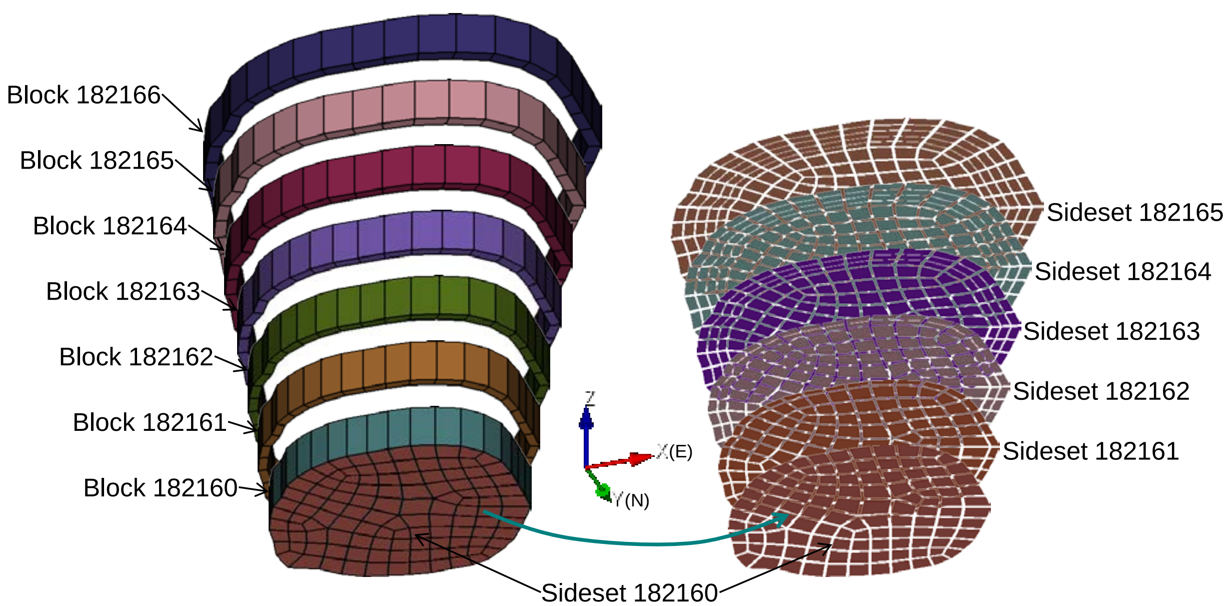


Figure 60: Inner and onion skin blocks and side sets of BC-18 cavern roof block

6.4.7. Cavern slice block

BC-18 consists of 100 cavern slice blocks because the height of the cavern is 2000 ft. The steps of creating the slice block, whose bottom elevation is -3080 ft, will be described in this section as an example. The cavern slice block is created through **`bot_3080.jou`** (File 60).

The command line of **`vtx_3080.jou`** (File 61) in File 60 is the Cubit journal file to create the vertices for the BC-18 cavern slice block. The elevations of the top and bottom of the block are -3060 ft and -3080 ft, respectively.

The cavern slice block is created through **`create_vol.jou`** (File 50) as shown Figure 61.

- First step: the top and bottom of inner and six skin perimeters of seven volumes consist of 36 curves created by `create curve vertex` which connects to vertices.
- Second step: Two surfaces on top and bottom of the slice volumes are created with 36 curves through `create surface curve`.
- Third step: Seven volumes are created by `create volume loft surface` through matching the vertices on top and bottom surfaces one by one using `match vertex`.
- Fourth step: Seven volumes are overlapped. To separate seven volumes, the outside volume is cut by the side surface of the inside volume through `webcut body ~ tool body ~`. The 6th skin volume is cut by the 5th skin volume through `webcut body {TNSB+VI6+1} tool body {TNSB+VI5+1}`. The 5th skin volume is cut by the 4th skin volume through `webcut body {TNSB+VI5+1} tool body {TNSB+VI4+1}`. This routine repeats four times more. The duplicated cavern volume are deleted using `delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}`.
- Fifth step: During matching two vertices on the top and bottom perimeters, unexpected vertices are born occasionally on the vertical curves as shown in Figure 61. The unexpected vertices yield unexpected mesh lines which cause skew mesh shape, so they have to be removed through `simplify curve all except curve {TVTX0} to {TNVTX}`.
- Sixth step: To remove the duplicated geometries such as vertex, curve, surface, etc., all geometries are merged through `merge all`. The unnecessary surfaces generated during the process are removed using `delete body 1 to {TNSB}`.

To create the mesh in the created cavern slice volumes, **`mesh_wall.jou`** (File 62) is used. Figure 62 shows the steps to create the mesh into the cavern slice volumes. As the first step, the upper salt block is imported on the created volumes, and the bottom surfaces of the imported volumes and the top surfaces of the created volumes are merged to transfer the mesh. As the next step, the vertical curves of the created volumes are meshed with one interval because the thickness of the created volumes is 20 ft, and then the volumes in the created volumes are meshed entirely. As the third step, the imported volumes are deleted. As the last step, The meshed inner and six skin volumes are defined as `Element Blocks 183080, 183081, 183082, 1823083, 183084, 183085,` and `183086`, respectively. The inside surfaces of `Element Blocks 183081, 183082, 1823083, 183084, 183085,` and `183086` are defined as `Sidesets 183080, 183081, 183082, 183083, 183084`, and `183085`, respectively.

The side sets represent the wall of the cavern. `Sidesets 183080` is the wall of the original cavern, `Sidesets 183081` is the wall of the cavern after the first drawdown leach. Thus, the inside surfaces of `Element Blocks 183081` is defined as `Sideset 183080`. In the same manner, `Sideset 183085` is the wall of the cavern after the fifth drawdown leaches. The sixth `Element Block 183086` is considered like one onion skin of the Non-SPR cavern to check the analysis results at the wall of the cavern after the fifth drawdown leach. Each inner and six skin slice blocks at every 20 ft elevation will be combined in the GJOIN step.

The meshed cavern slice blocks are saved through the command scripts in **`save.jou`** (File 21) (replacing 001 with 018).

Through the similar procedure, 100 cavern slice blocks are created by executing **`bot_2180.jou`** through **`bot_4160.jou`** in File 48.

File 60: bot_3080.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_3080.jou")}
# Create Curve =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 61: vtx_3080.jou

```
# Top elevation       : {TELE=       -3060  } ft
# Bottom elevation    : {BELE=       -3080  } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
# created 2nd drawdown skin volume     : {VDL2=TNSB+3}
# created 3rd drawdown skin volume     : {VDL3=TNSB+4}
# created 4th drawdown skin volume     : {VDL4=TNSB+5}
# created 5th drawdown skin volume     : {VDL5=TNSB+6}
# created 6th drawdown skin volume     : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  720.70         77.78          -3060
create vertex  719.59         95.95          -3060
create vertex  710.27         111.68         -30600
.
.                                                   36 lines   cavern perimeter
.
create vertex  704.38         28.72          -3060
create vertex  713.45         43.35          -3060
create vertex  719.55         59.98          -3060
### Drawdown 1 ----------------------------------
create vertex  728.10         78.46          -3060
create vertex  726.90         97.94          -3060
create vertex  716.91         114.81         -3060
.
.                                                              1st skin perimeter
.
create vertex  710.60         25.84          -3060
create vertex  720.32         41.54          -3060
create vertex  726.86         59.36          -3060
### Drawdown 2 ----------------------------------
create vertex  736.03         79.18          -3060
create vertex  734.75         100.08         -3060
create vertex  724.04         118.17         -3060
.
.                                                              2nd skin perimeter
.
create vertex  717.26         22.76          -3060
create vertex  727.69         39.59          -3060
create vertex  734.71         58.71          -3060
### Drawdown 3 ----------------------------------
create vertex  744.54         79.96          -3060
create vertex  743.16         102.37         -3060
create vertex  731.67         121.77         -3060
.
.                                                              3rd skin perimeter   Top
.
create vertex  724.41         19.46          -3060
create vertex  735.60         37.50          -3060
create vertex  743.12         58.00          -3060
### Drawdown 4 ----------------------------------
create vertex  753.66         80.80          -3060
create vertex  752.19         104.83         -3060
create vertex  739.86         125.63         -3060
.
.                                                              4th skin perimeter
.
create vertex  732.07         15.91          -3060
create vertex  744.07         35.26          -3060
create vertex  752.14         57.25          -3060
### Drawdown 5 ----------------------------------
create vertex  763.44         81.69          -3060
create vertex  761.86         107.46         -3060
create vertex  748.65         129.77         -3060
.
.                                                              5th skin perimeter
.
create vertex  740.29         12.11          -3060
create vertex  753.16         32.86          -3060
create vertex  761.81         56.44          -3060
### Drawdown 6 ----------------------------------
create vertex  773.93         82.65          -3060
create vertex  772.24         110.28         -3060
create vertex  758.07         134.21         -3060
.
.                                                              6th skin perimeter
.
create vertex  749.11         8.03           -3060
create vertex  762.90         30.29          -3060
create vertex  772.18         55.57          -3060

(To be continued)
```

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  746.45         84.59          -3080
create vertex  743.63         104.65         -3080
create vertex  743.73         127.02         -3080
.
.
.
create vertex  709.19         38.08          -3080
create vertex  727.85         48.57          -3080
create vertex  740.91         64.89          -3080
### Drawdown 1 ----------------------------------
create vertex  754.84         85.27          -3080
create vertex  751.81         106.78         -3080
create vertex  751.92         130.77         -3080
.
.
.
create vertex  714.88         35.39          -3080
create vertex  734.89         46.64          -3080
create vertex  748.90         64.14          -3080
### Drawdown 2 ----------------------------------
create vertex  763.83         86.00          -3080
create vertex  760.58         109.07         -3080
create vertex  760.70         134.79         -3080
.
.
.
create vertex  720.98         32.51          -3080
create vertex  742.44         44.57          -3080
create vertex  757.46         63.34          -3080
### Drawdown 3 ----------------------------------
create vertex  773.48         86.78          -3080
create vertex  769.99         111.52         -3080
create vertex  770.12         139.11         -3080
.
.
.
create vertex  727.53         29.42          -3080
create vertex  750.54         42.36          -3080
create vertex  766.65         62.48          -3080
### Drawdown 4 ----------------------------------
create vertex  783.82         87.62          -3080
create vertex  780.08         114.15         -3080
create vertex  780.22         143.73         -3080
.
.
.
create vertex  734.54         26.10          -3080
create vertex  759.22         39.98          -3080
create vertex  776.49         61.56          -3080
### Drawdown 5 ----------------------------------
create vertex  794.91         88.51          -3080
create vertex  790.90         116.97         -3080
create vertex  791.05         148.69         -3080
.
.
.
create vertex  742.07         22.55          -3080
create vertex  768.53         37.43          -3080
create vertex  787.05         60.57          -3080
### Drawdown 6 ----------------------------------
create vertex  806.80         89.48          -3080
create vertex  802.50         119.99         -3080
create vertex  802.66         154.01         -3080
.
.
.
create vertex  750.14         18.74          -3080
create vertex  778.52         34.70          -3080
create vertex  798.38         59.52          -3080
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Bottom

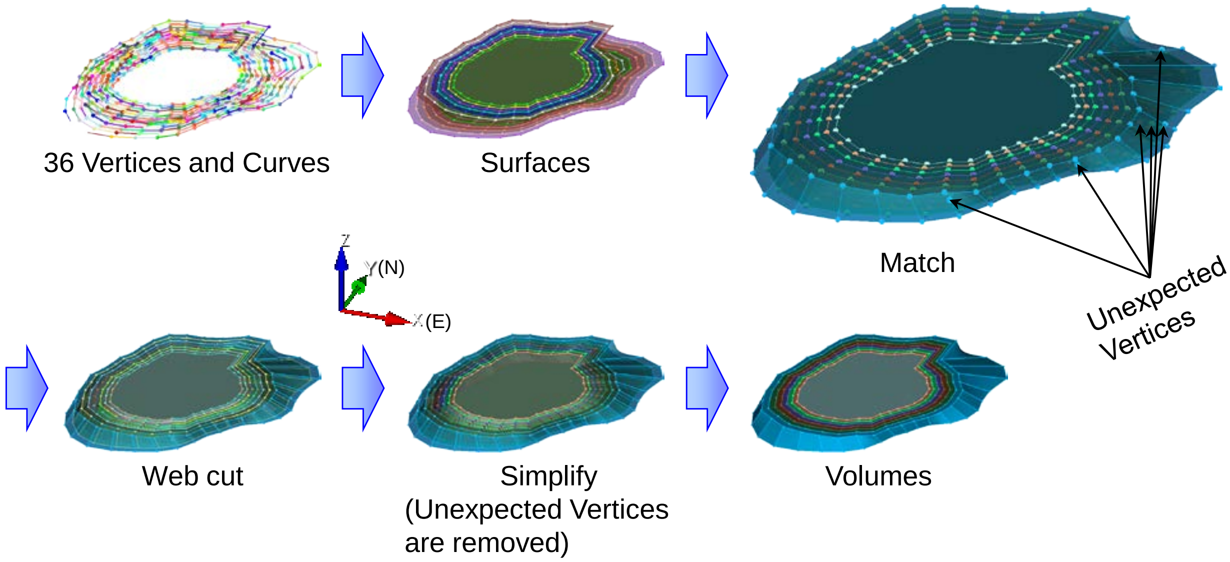


Figure 61: Steps to create BC-18 cavern slice volume whose bottom elevation is -3080 ft

File 62: mesh_wall.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL6} interval 1
mesh volume {VDL0} to {VDL6}
#### Smoothing ------------------------
surface in sdl0b smooth scheme cond
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks =====================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
# Define Sideset ====================================================
sideset {BID+VI0} surface in sdl0w wrt volume {VDL1}
sideset {BID+VI1} surface in sdl1w wrt volume {VDL2}
sideset {BID+VI2} surface in sdl2w wrt volume {VDL3}
sideset {BID+VI3} surface in sdl3w wrt volume {VDL4}
sideset {BID+VI4} surface in sdl4w wrt volume {VDL5}
sideset {BID+VI5} surface in sdl5w wrt volume {VDL6}
```

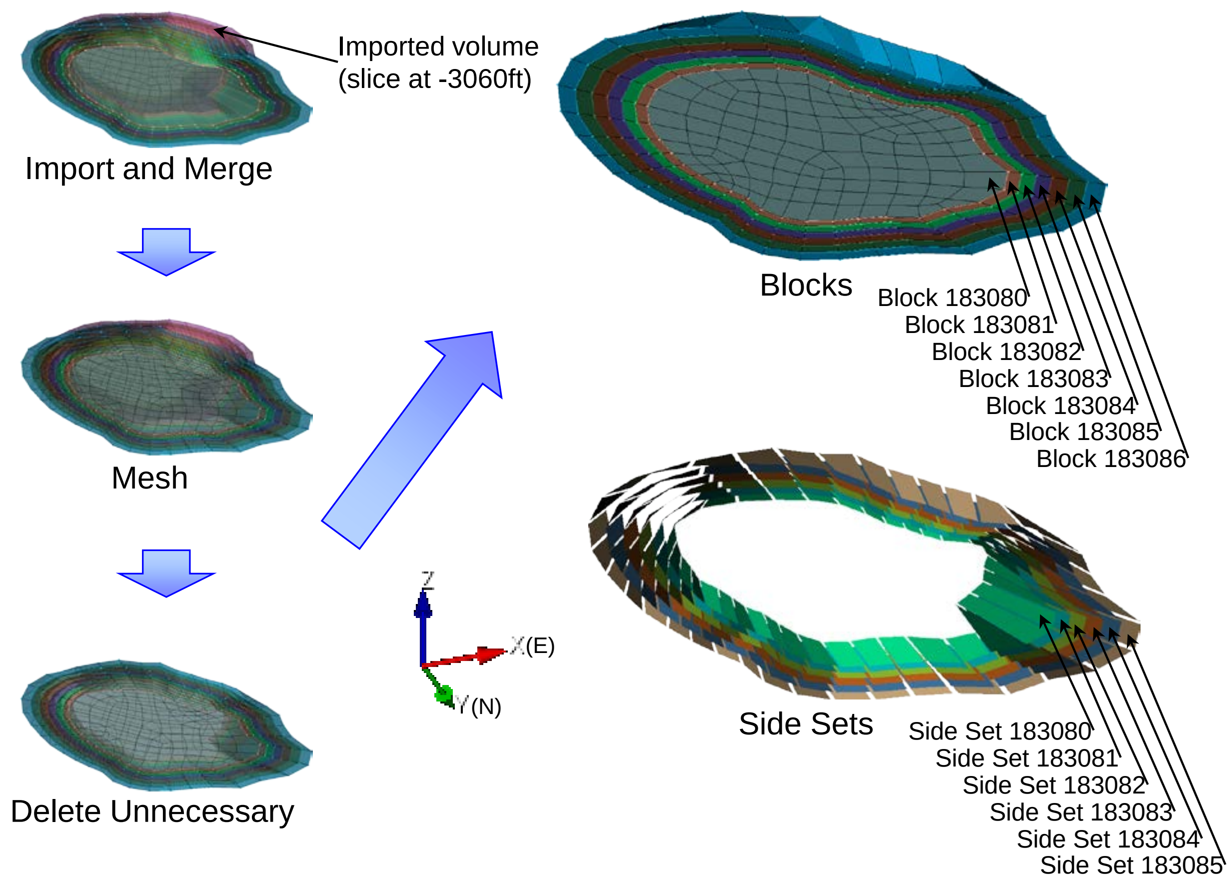


Figure 62: Steps to mesh BC-18 cavern slice at which bottom is -3080 ft

6.4.8. Floor block

The floor block is constructed by using **`bot_4180_floor.jou`** (File 63).

The command line of **`vtx_4180.jou`** (File 64) in File 63 is the Cubit journal file to create the vertices for the BC-18 cavern floor. The elevations of the top and bottom of the floor block are -4160 ft and -4180 ft, respectively. The cavern floor volumes are created using **`create_vol.jou`** (File 50) as shown Figure 63.

To create the mesh in the volumes, **`mesh_floor.jou`** (File 65) is used. Figure 64 shows the steps to create the mesh into the cavern floor. As the first step, the cavern slice block right above the floor block is imported, and the bottom surfaces of the upper slice block and the top surfaces of the floor block are merged to transfer the mesh. As the next step, the vertical curves on the floor block are meshed with one interval because the thickness of the floor block is 20 ft, and then the volumes in the floor block are meshed entirely. As the third step, the imported slice block is deleted. As the last step, The meshed inner and six skin volumes are defined as `Element Blocks 184180, 184181, 184182, 184183, 184184, 184185`, and `184186`, respectively. The side sets of the top surfaces of the blocks are defined as `Sidesets 184180, 184181, 184182, 184183, 184184,` and `184185`, respectively, as shown Figure 65.

The side sets represent the floor of the cavern. `Sidesets 184180` is the floor of the original cavern, `Sideset 184181` is the floor of the cavern after the first drawdown leach. Thus, the top surfaces of

`Element Blocks 184180` and `184181` are defined as `Sideset 184181`. In the same manner, `Sideset 184185` is the floor of the cavern after the fifth drawdown leaches. Thus, the top surfaces of the `Element Blocks 184180, 184181, 184182, 184183, 184184`, and `184185` are defined as `Sideset 184185`. The sixth `Element Block 184186` is considered like one onion skin of the Non-SPR cavern to check the analysis results at the floor of the cavern. The inner and six skin blocks will be combined into one floor block in the GJOIN step.

The meshed floor block is saved through the command scripts in **`save.jou`** (File 21) (replacing 001 with 018).

File 63: bot_4180_floor.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_4180.jou")}
# Create Curve =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_floor.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 64: vtx_4180.jou

```
# Top elevation       : {TELE=       -4160   } ft
# Bottom elevation    : {BELE=       -4180   } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
# created 2nd drawdown skin volume     : {VDL2=TNSB+3}
# created 3rd drawdown skin volume     : {VDL3=TNSB+4}
# created 4th drawdown skin volume     : {VDL4=TNSB+5}
# created 5th drawdown skin volume     : {VDL5=TNSB+6}
# created 6th drawdown skin volume     : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex ====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  850.48          71.69           -4160
create vertex  841.31          114.91          -4160
create vertex  823.16          154.85          -4160
.
.
.
create vertex  830.54          -59.21          -4160
create vertex  853.18          -19.02          -4160
create vertex  855.81          26.92           -4160
### Drawdown 1 ----------------------------------
create vertex  868.81          73.31           -4160
create vertex  858.97          119.66          -4160
create vertex  839.50          162.49          -4160
.
.
.
create vertex  847.42          -67.07          -4160
create vertex  871.69          -23.96          -4160
create vertex  874.52          25.30           -4160
### Drawdown 2 ----------------------------------
create vertex  888.46          75.05           -4160
create vertex  877.90          124.76          -4160
create vertex  857.03          170.68          -4160
.
.
.
create vertex  865.53          -75.49          -4160
create vertex  891.55          -29.26          -4160
create vertex  894.58          23.57           -4160
### Drawdown 3 ----------------------------------
create vertex  909.53          76.91           -4160
create vertex  898.21          130.22          -4160
create vertex  875.83          179.46          -4160
.
.
.
create vertex  884.94          -84.52          -4160
create vertex  912.85          -34.95          -4160
create vertex  916.10          21.70           -4160
### Drawdown 4 ----------------------------------
create vertex  932.13          78.91           -4160
create vertex  919.99          136.07          -4160
create vertex  895.99          188.89          -4160
.
.
.
create vertex  905.76          -94.21          -4160
create vertex  935.69          -41.05          -4160
create vertex  939.17          19.71           -4160
### Drawdown 5 ----------------------------------
create vertex  956.36          81.05           -4160
create vertex  943.34          142.35          -4160
create vertex  917.60          198.99          -4160
.
.
.
create vertex  928.08          -104.60         -4160
create vertex  960.18          -47.59          -4160
create vertex  963.92          17.57           -4160
### Drawdown 6 ----------------------------------
create vertex  982.35          83.35           -4160
create vertex  968.39          149.09          -4160
create vertex  940.78          209.82          -4160
.
.
.
create vertex  952.02          -115.74         -4160
create vertex  986.44          -54.60          -4160
create vertex  990.45          15.27           -4160

(To be continued)
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Top

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  850.48         71.69          -4180
create vertex  841.31         114.91         -4180
create vertex  823.16         154.85         -4180
.
.
.
create vertex  830.54         -59.21         -4180
create vertex  853.18         -19.02         -4180
create vertex  855.81         26.92          -4180
### Drawdown 1 ----------------------------------
create vertex  868.81         73.31          -4180
create vertex  858.97         119.66         -4180
create vertex  839.50         162.49         -4180
.
.
.
create vertex  847.42         -67.07         -4180
create vertex  871.69         -23.96         -4180
create vertex  874.52         25.30          -4180
### Drawdown 2 ----------------------------------
create vertex  888.46         75.05          -4180
create vertex  877.90         124.76         -4180
create vertex  857.03         170.68         -4180
.
.
.
create vertex  865.53         -75.49         -4180
create vertex  891.55         -29.26         -4180
create vertex  894.58         23.57          -4180
### Drawdown 3 ----------------------------------
create vertex  909.53         76.91          -4180
create vertex  898.21         130.22         -4180
create vertex  875.83         179.46         -4180
.
.
.
create vertex  884.94         -84.52         -4180
create vertex  912.85         -34.95         -4180
create vertex  916.10         21.70          -4180
### Drawdown 4 ----------------------------------
create vertex  932.13         78.91          -4180
create vertex  919.99         136.07         -4180
create vertex  895.99         188.89         -4180
.
.
.
create vertex  905.76         -94.21         -4180
create vertex  935.69         -41.05         -4180
create vertex  939.17         19.71          -4180
### Drawdown 5 ----------------------------------
create vertex  956.36         81.05          -4180
create vertex  943.34         142.35         -4180
create vertex  917.60         198.99         -4180
.
.
.
create vertex  928.08         -104.60        -4180
create vertex  960.18         -47.59         -4180
create vertex  963.92         17.57          -4180
### Drawdown 6 ----------------------------------
create vertex  982.35         83.35          -4180
create vertex  968.39         149.09         -4180
create vertex  940.78         209.82         -4180
.
.
.
create vertex  952.02         -115.74        -4180
create vertex  986.44         -54.60         -4180
create vertex  990.45         15.27          -4180
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Bottom

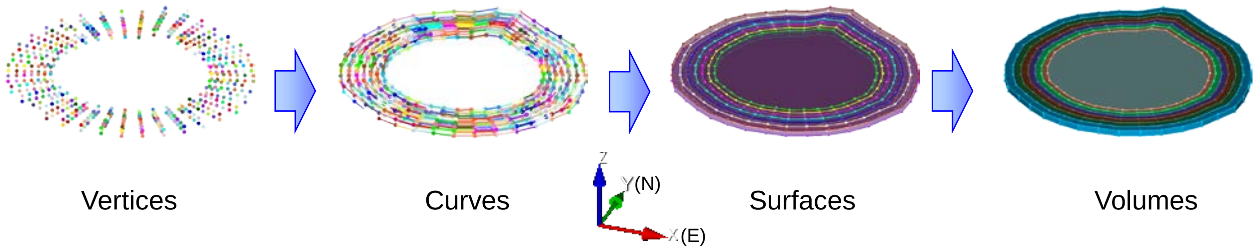


Figure 63: Vertices, curves, surfaces, and volumes of BC-18 cavern floor block

File 65: mesh_floor.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 2 ----------------------------------
curve in cdl2w interval {(TELE-BELE)/TL}
curve in cdl2w scheme equal
mesh curve in cdl2w
### Drawdown 3 ----------------------------------
curve in cdl3w interval {(TELE-BELE)/TL}
curve in cdl3w scheme equal
mesh curve in cdl3w
### Drawdown 4 ----------------------------------
curve in cdl4w interval {(TELE-BELE)/TL}
curve in cdl4w scheme equal
mesh curve in cdl4w
### Drawdown 5 ----------------------------------
curve in cdl5w interval {(TELE-BELE)/TL}
curve in cdl5w scheme equal
mesh curve in cdl5w
### Drawdown 6 ----------------------------------
curve in cdl6w interval {(TELE-BELE)/TL}
curve in cdl6w scheme equal
mesh curve in cdl6w

(To be continued)
```

```
## Mesh volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VDL0} to {VDL6} interval 1
mesh volume {VDL0} to {VDL6}
# Delete unnecessaries ============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ===================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
# Define Sideset ==================================================
### Drawdown 0 (Initial Cavern) -----------------
sideset {BID+VI0} surface in sdl0t wrt volume {VDL0}
### Drawdown 1 ----------------------------------
sideset {BID+VI1} surface in sdl1t wrt volume {VDL1}
sideset {BID+VI1} surface in sdl0t wrt volume {VDL0}
### Drawdown 2 ----------------------------------
sideset {BID+VI2} surface in sdl2t wrt volume {VDL2}
sideset {BID+VI2} surface in sdl1t wrt volume {VDL1}
sideset {BID+VI2} surface in sdl0t wrt volume {VDL0}
### Drawdown 3 ----------------------------------
sideset {BID+VI3} surface in sdl3t wrt volume {VDL3}
sideset {BID+VI3} surface in sdl2t wrt volume {VDL2}
sideset {BID+VI3} surface in sdl1t wrt volume {VDL1}
sideset {BID+VI3} surface in sdl0t wrt volume {VDL0}
### Drawdown 4 ----------------------------------
sideset {BID+VI4} surface in sdl4t wrt volume {VDL4}
sideset {BID+VI4} surface in sdl3t wrt volume {VDL3}
sideset {BID+VI4} surface in sdl2t wrt volume {VDL2}
sideset {BID+VI4} surface in sdl1t wrt volume {VDL1}
sideset {BID+VI4} surface in sdl0t wrt volume {VDL0}
### Drawdown 5 ----------------------------------
sideset {BID+VI5} surface in sdl5t wrt volume {VDL5}
sideset {BID+VI5} surface in sdl4t wrt volume {VDL4}
sideset {BID+VI5} surface in sdl3t wrt volume {VDL3}
sideset {BID+VI5} surface in sdl2t wrt volume {VDL2}
sideset {BID+VI5} surface in sdl1t wrt volume {VDL1}
sideset {BID+VI5} surface in sdl0t wrt volume {VDL0}
```

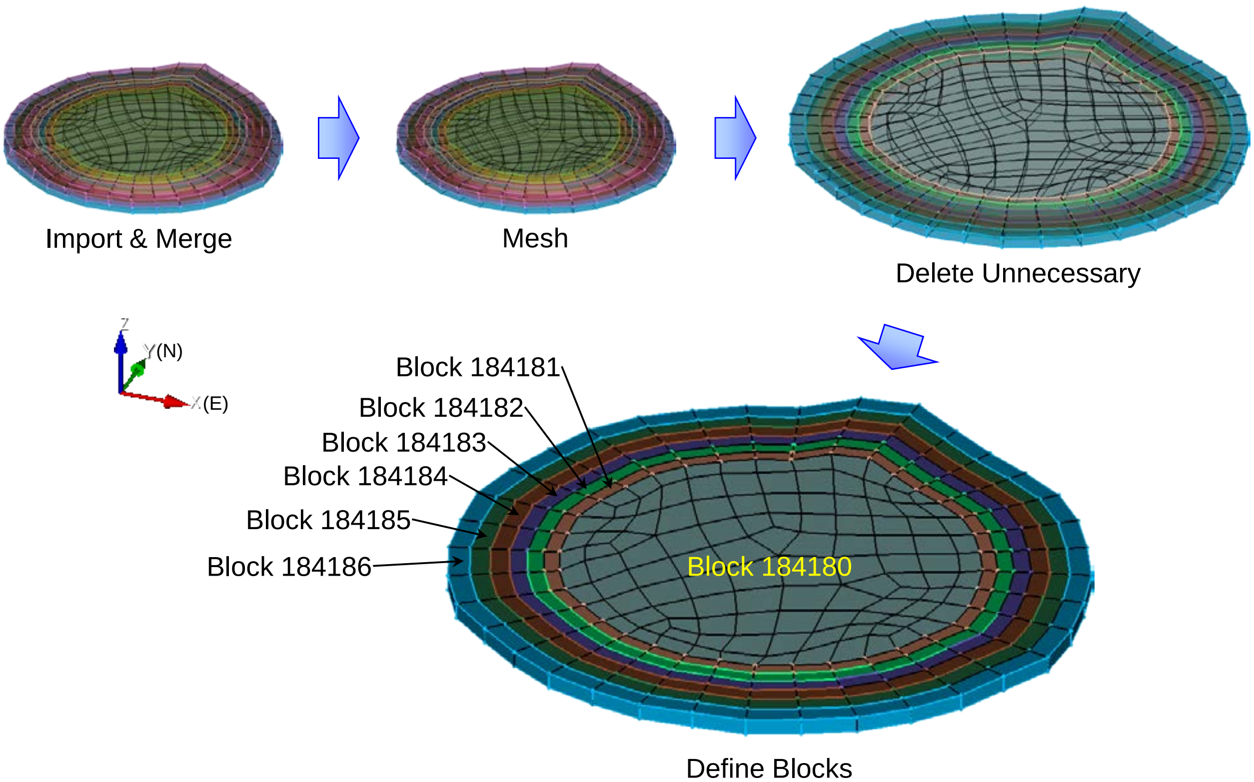


Figure 64: Steps to mesh the cavern floor of BC-18

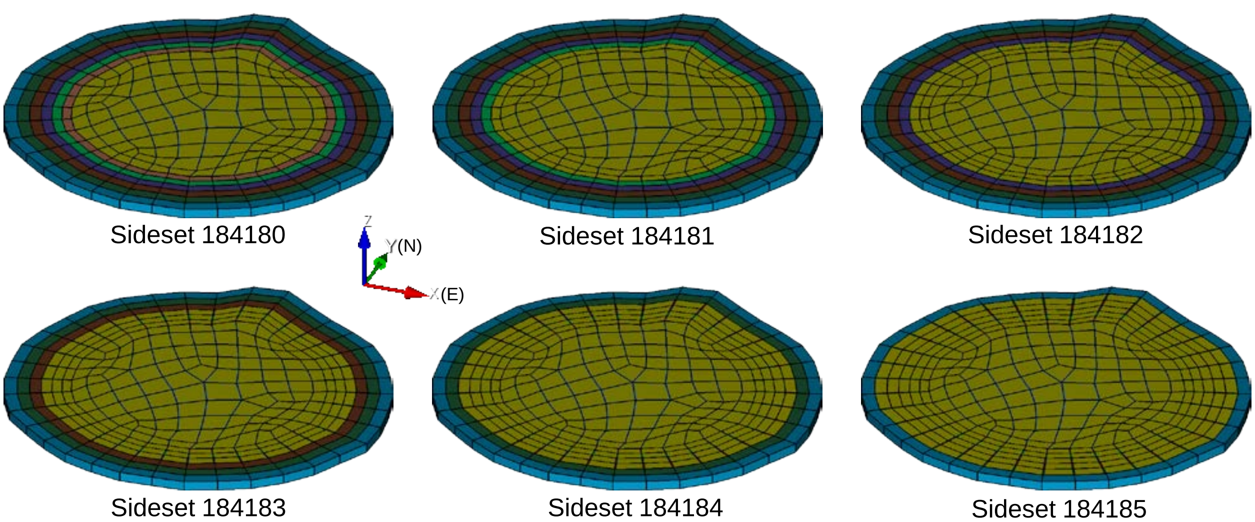


Figure 65: Sidesets in yellow of BC-18 cavern floor

6.4.9. Lower salt block

The upper salt block is constructed by using **`bot_6400_below.jou`** (File 66).

The command line of **`vtx_6400.jou`** (File 67) in File 66 is the Cubit journal file to create the vertices for the BC-18 cavern column salt block below the cavern. The elevations of the top and bottom of the block are -4180 ft and -6400 ft, respectively. The X- and Y- coordinates on the top are the same as those on the bottom. To create the cavern column volumes, **`create_vol.jou`** (File

50) is used. In the same manner as the previous section, the cavern column volumes are created as shown Figure 66.

To mesh the block, the command line of **`mesh_below_wo_ss.jou`** (File 68) in File 66 is used. Figure 67 shows the steps to create the mesh into the lower salt block. As the first step, the floor block is imported right above the lower salt block, and the bottom surfaces of the floor block and the top surfaces of the lower salt block are merged to transfer the mesh. As the next step, the vertical curves of the volumes in the lower salt block 2220 ft height are divided by 20 ft, and then 111 intervals are created, and then the volumes in the lower salt block are meshed entirely. As the third step, the imported volumes are deleted. As the last step, meshed inner and six skin volumes are defined as `Element Blocks 186400, 186401, 186402, 186403, 186404, 186405`, and `186406`, respectively. The node set on the bottom of the lower salt block is defined as `Nodeset 180003` which will be added on the bottom node set of the entire model.

The meshed lower salt block is saved through the command scripts in **`save_wo_ss.jou`** (File 28) (replacing 001 with 018).

File 66: bot_6400_below.jou

```
# Setup environment  ===============================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6400.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_below_wo_ss.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ss.jou")}
#
exit
```

File 67: vtx_6400.jou

```
# Top elevation       : {TELE=       -4180   } ft
# Bottom elevation    : {BELE=       -6400   } ft
# Cavern ID    : {CID=18*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices          : {NVTX=36}
# number of drowdown leaches  : {NDL=6}
# number of volumes           : {NVOL=NDL+1}
# total number of vertices in one layer      : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer  : {TNSB=NVOL*2}
# original cavern volume ID   : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# 2nd drawdown skin volume ID : {VI2=2}
# 3rd drawdown skin volume ID : {VI3=3}
# 4th drawdown skin volume ID : {VI4=4}
# 5th drawdown skin volume ID : {VI5=5}
# 6th drawdown skin volume ID : {VI6=6}
# original cavern volume top surface ID  : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# 2nd drawdown skin volume top surface ID: {TSI2=3}
# 3rd drawdown skin volume top surface ID: {TSI3=4}
# 4th drawdown skin volume top surface ID: {TSI4=5}
# 5th drawdown skin volume top surface ID: {TSI5=6}
# 6th drawdown skin volume top surface ID: {TSI6=7}
# original cavern volume bot surface ID  : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# 2nd drawdown skin volume bot surface ID: {BSI2=TSI2+NVOL}
# 3rd drawdown skin volume bot surface ID: {BSI3=TSI3+NVOL}
# 4th drawdown skin volume bot surface ID: {BSI4=TSI4+NVOL}
# 5th drawdown skin volume bot surface ID: {BSI5=TSI5+NVOL}
# 6th drawdown skin volume bot surface ID: {BSI6=TSI6+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
# created 2nd drawdown skin volume     : {VDL2=TNSB+3}
# created 3rd drawdown skin volume     : {VDL3=TNSB+4}
# created 4th drawdown skin volume     : {VDL4=TNSB+5}
# created 5th drawdown skin volume     : {VDL5=TNSB+6}
# created 6th drawdown skin volume     : {VDL6=TNSB+7}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x

(To be continued)
```

```
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  850.48         71.69          -4180
create vertex  841.31         114.91         -4180
create vertex  823.16         154.85         -4180
.
.
.
create vertex  830.54         -59.21         -4180
create vertex  853.18         -19.02         -4180
create vertex  855.81         26.92          -4180
### Drawdown 1 ----------------------------------
create vertex  868.81         73.31          -4180
create vertex  858.97         119.66         -4180
create vertex  839.50         162.49         -4180
.
.
.
create vertex  847.42         -67.07         -4180
create vertex  871.69         -23.96         -4180
create vertex  874.52         25.30          -4180
### Drawdown 2 ----------------------------------
create vertex  888.46         75.05          -4180
create vertex  877.90         124.76         -4180
create vertex  857.03         170.68         -4180
.
.
.
create vertex  865.53         -75.49         -4180
create vertex  891.55         -29.26         -4180
create vertex  894.58         23.57          -4180
### Drawdown 3 ----------------------------------
create vertex  909.53         76.91          -4180
create vertex  898.21         130.22         -4180
create vertex  875.83         179.46         -4180
.
.
.
create vertex  884.94         -84.52         -4180
create vertex  912.85         -34.95         -4180
create vertex  916.10         21.70          -4180
### Drawdown 4 ----------------------------------
create vertex  932.13         78.91          -4180
create vertex  919.99         136.07         -4180
create vertex  895.99         188.89         -4180
.
.
.
create vertex  905.76         -94.21         -4180
create vertex  935.69         -41.05         -4180
create vertex  939.17         19.71          -4180
### Drawdown 5 ----------------------------------
create vertex  956.36         81.05          -4180
create vertex  943.34         142.35         -4180
create vertex  917.60         198.99         -4180
.
.
.
create vertex  928.08         -104.60        -4180
create vertex  960.18         -47.59         -4180
create vertex  963.92         17.57          -4180
### Drawdown 6 ----------------------------------
create vertex  982.35         83.35          -4180
create vertex  968.39         149.09         -4180
create vertex  940.78         209.82         -4180
.
.
.
create vertex  952.02         -115.74        -4180
create vertex  986.44         -54.60         -4180
create vertex  990.45         15.27          -4180
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Top

```
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  850.48          71.69           -6400
create vertex  841.31          114.91          -6400
create vertex  823.16          154.85          -6400
.
.
.
create vertex  830.54          -59.21          -6400
create vertex  853.18          -19.02          -6400
create vertex  855.81          26.92           -6400
### Drawdown 1 ----------------------------------
create vertex  868.81          73.31           -6400
create vertex  858.97          119.66          -6400
create vertex  839.50          162.49          -6400
.
.
.
create vertex  847.42          -67.07          -6400
create vertex  871.69          -23.96          -6400
create vertex  874.52          25.30           -6400
### Drawdown 2 ----------------------------------
create vertex  888.46          75.05           -6400
create vertex  877.90          124.76          -6400
create vertex  857.03          170.68          -6400
.
.
.
create vertex  865.53          -75.49          -6400
create vertex  891.55          -29.26          -6400
create vertex  894.58          23.57           -6400
### Drawdown 3 ----------------------------------
create vertex  909.53          76.91           -6400
create vertex  898.21          130.22          -6400
create vertex  875.83          179.46          -6400
.
.
.
create vertex  884.94          -84.52          -6400
create vertex  912.85          -34.95          -6400
create vertex  916.10          21.70           -6400
### Drawdown 4 ----------------------------------
create vertex  932.13          78.91           -6400
create vertex  919.99          136.07          -6400
create vertex  895.99          188.89          -6400
.
.
.
create vertex  905.76          -94.21          -6400
create vertex  935.69          -41.05          -6400
create vertex  939.17          19.71           -6400
### Drawdown 5 ----------------------------------
create vertex  956.36          81.05           -6400
create vertex  943.34          142.35          -6400
create vertex  917.60          198.99          -6400
.
.
.
create vertex  928.08          -104.60         -6400
create vertex  960.18          -47.59          -6400
create vertex  963.92          17.57           -6400
### Drawdown 6 ----------------------------------
create vertex  982.35          83.35           -6400
create vertex  968.39          149.09          -6400
create vertex  940.78          209.82          -6400
.
.
.
create vertex  952.02          -115.74         -6400
create vertex  986.44          -54.60          -6400
create vertex  990.45          15.27           -6400
```

36 lines

cavern perimeter

1st skin perimeter

2nd skin perimeter

3rd skin perimeter

4th skin perimeter

5th skin perimeter

6th skin perimeter

Bottom

File 68: mesh_below_wo_ss.jou

```
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_6dd.jou")}
# Mesh =============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
### Drawdown 2 ----------------------------------
curve in cdl2w interval {(TELE-BELE)/TL}
curve in cdl2w scheme equal
mesh curve in cdl2w
### Drawdown 3 ----------------------------------
curve in cdl3w interval {(TELE-BELE)/TL}
curve in cdl3w scheme equal
mesh curve in cdl3w
### Drawdown 4 ----------------------------------
curve in cdl4w interval {(TELE-BELE)/TL}
curve in cdl4w scheme equal
mesh curve in cdl4w
### Drawdown 5 ----------------------------------
curve in cdl5w interval {(TELE-BELE)/TL}
curve in cdl5w scheme equal
mesh curve in cdl5w
### Drawdown 6 ----------------------------------
curve in cdl6w interval {(TELE-BELE)/TL}
curve in cdl6w scheme equal
mesh curve in cdl6w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
volume {VDL0} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL0}
### Drawdown 1 ----------------------------------
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
### Drawdown 2 ----------------------------------
volume {VDL2} scheme Sweep  source surface in sdl2t target surface in sdl2b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL2}
### Drawdown 3 ----------------------------------
volume {VDL3} scheme Sweep  source surface in sdl3t target surface in sdl3b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL3}
### Drawdown 4 ----------------------------------
volume {VDL4} scheme Sweep  source surface in sdl4t target surface in sdl4b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL4}
### Drawdown 5 ----------------------------------
volume {VDL5} scheme Sweep  source surface in sdl5t target surface in sdl5b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL5}
### Drawdown 6 ----------------------------------
volume {VDL6} scheme Sweep  source surface in sdl6t target surface in sdl6b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL6}

(To be continued)
```

```
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete sideset {TID} to {TID+NDL-1}
delete volume {(VDL0+NDL)*2} to {(VDL0+NDL)*2+NDL}
# Define Blocks ======================================================
block {BID+VI0} volume {VDL0}
block {BID+VI1} volume {VDL1}
block {BID+VI2} volume {VDL2}
block {BID+VI3} volume {VDL3}
block {BID+VI4} volume {VDL4}
block {BID+VI5} volume {VDL5}
block {BID+VI6} volume {VDL6}
# Define Node Set ======================================================
nodeset {CID+3} surface in bsurf
```

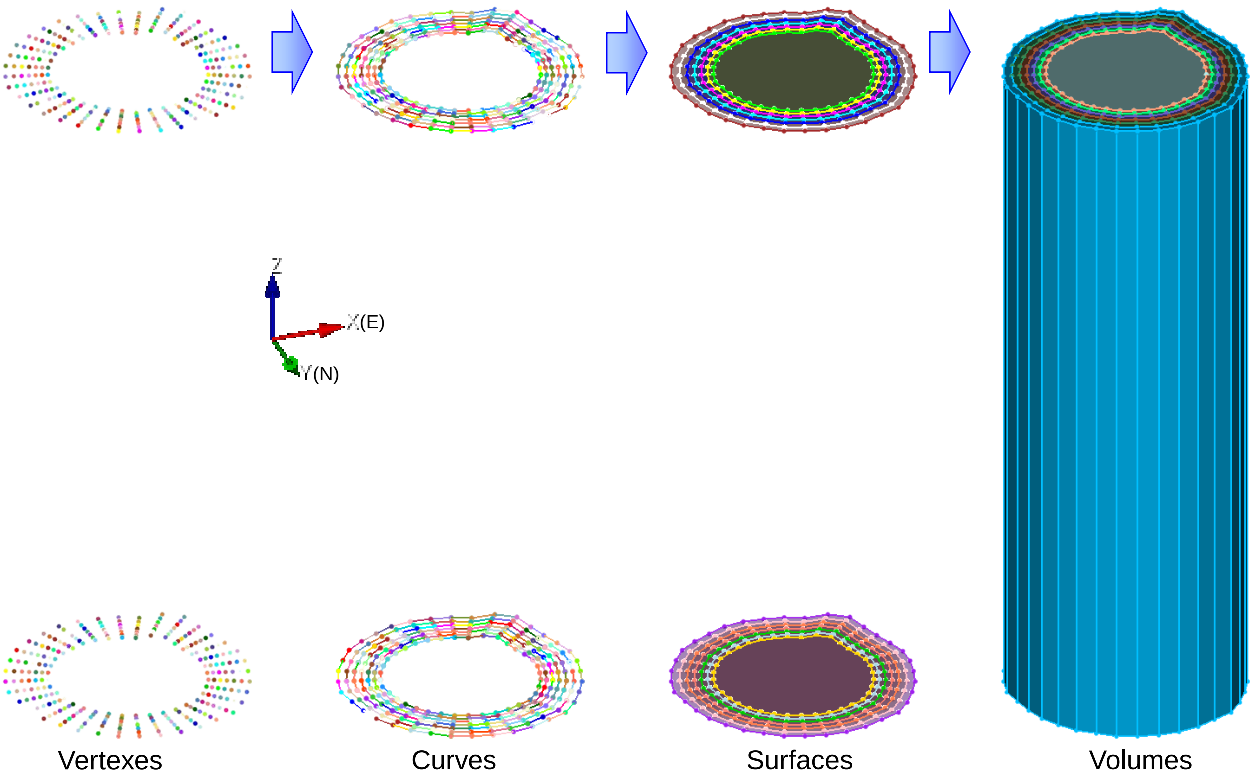


Figure 66: Vertices, curves, surfaces, and volumes of BC-18 column below the cavern

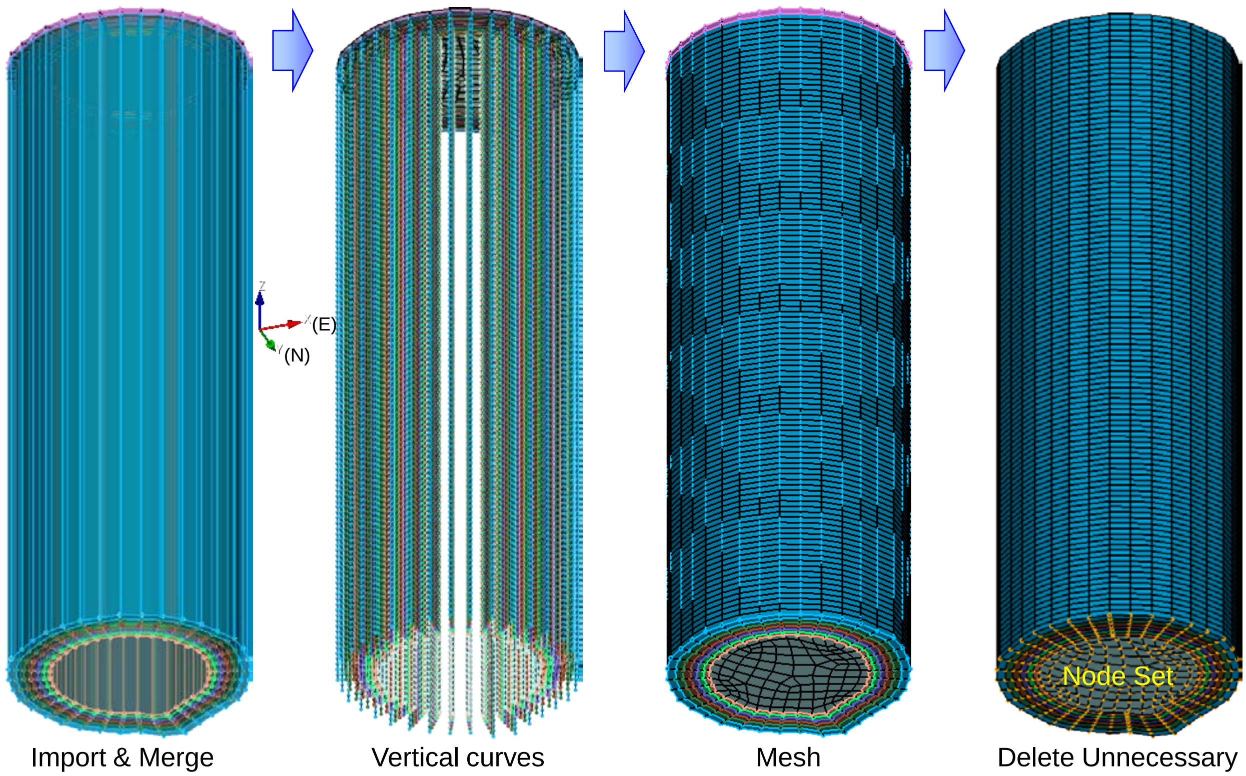


Figure 67: Steps to mesh the lower salt block under the cavern floor of BC-18

6.4.10. Cavern column

107 meshed blocks created in Section 6.4.3 through 6.4.9 are assembled into the BC-18 cavern column as shown Figure 68 through the GJOIN process on Redsky. **`bc018.gjn`** (File 69) shows the GJOIN scripts. The Genesis file of BC-18 cavern column is saved as **`bc018.g1`** into the directory of `/fscratch/bypark/BC_sonar/mesh/bc018g1/`. **`bc018.g1`** will be assembled into the entire model mesh named **`bc_20ft.g0`**.

The ID digits hereafter were described in Section 3.5. As the first step, two Genesis files **`bc_018_500.g0`** and **`bc_018_660.g0`** are combined with the tolerance of 1.E-02. The inner volume in the overburden layer (`Element Block 180500, GJOIN ID 1`) is assigned to the overburden block in the entire model as `Element Block 2018`. The first through the 6th skin volumes in the overburden layer (`Element Block 180501, 180502, 180503, 180504, 180505,and 180506`) are combined to `Element Block 2018`. The inner volume in the caprock layer (`Element Block 180660, GJOIN ID 8`) is assigned to the caprock block in the entire model as `Element Block 3018`. The first through the 6th skin volumes in the caprock layer (`Element Block 180661, 180662, 180663, 180664, 180665,and 180666`) is combined to `Element Block 3018`.

As the second step, the Genesis file **`bc018_680.g0`** is combined to the combined two Genesis files above. The inner volume in the interbed layer (`Element Block 180680, GJOIN ID 3`) is assigned to the interbed block in the entire model as `Element Block 8018`. The first through the 6th skin volumes in the interbed layer (`Element Block 180681, 180682, 180683, 180684, 180685,and 180686`) are combined to `Element Block 8018`.

As the third step, the Genesis file **bc018_2140.g0** is combined to three combined Genesis files above. The inner volume in the upper salt layer (Element Block 182140, GJOIN ID 4) is assigned to the salt block in the entire model as Element Block 1018. The first through the 6th skin volumes in the upper salt layer (Element Block 182141, 182142, 182143, 182144, 182145,and 182146) are combined to Element Block 1018.

As the fourth step, the Genesis file **bc018_2160.g0** is combined to four combined Genesis files above. The inner volume in the roof layer (Element Block 182160, GJOIN ID 5) is assigned to the salt block in the entire model as Element Block 101807. The cavern roof is regarded as cavern onion skin. The last digit 7 indicates the roof block. The first through the 6th skin volumes in the roof layer (Element Blocks 182161, 182162, 182163, 182164, 182165,and 182166) are assigned to the salt blocks in the entire model as 101817, 101827, 101837, 101847, 101857, and 101867, respectively. The side set on the bottom of the inner volume (Sideset 182160, GJOIN ID 1) is assigned to Sideset 180 which represents the ceiling of the cavern in the entire model. The side set on the bottom of the inner and the first skin volumes (Sideset 182161, GJOIN ID 2) is assigned to Sideset 181 which represents the ceiling of the cavern after the first drawdown in the entire model. In the same manner, the side set on the bottom of the inner and the first through the fifth skin volumes (Sideset 182165, GJOIN ID 6) is assigned to Sideset 185 which represents the ceiling of the cavern after the fifth drawdown in the entire model.

As the fifth step, the Genesis file **bc018_2180.g0** is combined to five combined Genesis files above. The inner cavern slice volume in the cavern layer (Element Block 182180, GJOIN ID 12) is assigned to the salt block in the entire model as Element Block 10180. The first through 6th cavern slice skin volumes (Element Blocks 182181, 182182, 182183, 182184, 182185,and 182186) are combined to Element Blocks 10181, 10182, 10183, 10184, 10185, and 10186, respectively. The side sets on the insides of the first through 6th cavern slice skin volumes (Sidesets 182180, 182181, 182182, 182183, 182184, and 182185) are assigned to the side sets in the entire model as Sideset 180, 181, 182, 183, 184, 185, respectively, which represent the walls of the cavern after the first through 5th drawdown leaches, respectively. Therefore, Sideset 180 represents the inside surface of the cavern because the side sets for the ceiling mentioned in the previous paragraph, the wall, and the floor below are combined into Sideset 180 together. In the same manner, Sideset 181, 182, 183, 184, and 185 represent the inside surfaces of the cavern after the first through 5th drawdown leaches, respectively.

As the sixth step, the Genesis file **bc018_2200.g0** is combined to six combined Genesis files above. The inner cavern slice volume in the cavern layer (Element Block 182200) is assigned to the salt block in the entire model as Element Block 10180. The first through 6th cavern slice skin volumes (Element Blocks 182201, 182202, 182203, 182204, 182205,and 182206) are combined to Element Blocks 10181, 10182, 10183, 10184, 10185, and 10186, respectively. The side sets on the insides of the first through 6th cavern slice skin volumes (Sidesets 182200, 182201, 182202, 182203, 182204, and 182205) are assigned to the side sets in the entire model as Sideset 180, 181, 182, 183, 184, 185, respectively like the volumes right above.

In the similar manner as the sixth step, the geneses files from **bc018_2220.g0** through **bc018_4160.g0** are combined.

As the next step, the Genesis file **bc018_4180.g0** is combined to 105 combined Genesis files above (BC-18 cavern column consists of 107 cavern slice blocks). The inner cavern slice volume in the floor layer (Element Block 184180, GJOIN ID 19) is assigned to the salt block in the entire model as Element Block 101809. The cavern floor is regarded as cavern onion skin. The last digit 9 indicates the floor block. The first through the 6th skin volumes in the floor layer (Element Blocks 184181, 184182, 184183, 184184, 184185,and 184186) are assigned to the salt blocks in the entire model as 101819, 101829, 101839, 101849, 101859, and 101869, respectively. The side set on the top of the inner volume (Sideset 184180) is assigned to Sideset 180 which represents the floor of the cavern in the entire model. Therefore, Sideset 180 represents the inside (ceiling, wall, and floor) of the cavern. The side set on the top of the inner and the first skin volumes (Sideset 182161) is assigned to Sideset 181 which represents the floor of the cavern after the first drawdown in the entire model. In the same manner, the side set on the top of the inner and the first through the fifth skin volumes (Sideset 182165) is assigned to Sideset 185 which represents the floor of the cavern after the fifth drawdown in the entire model. Therefore, Sidesets 181, 182, 183, 184, and 185 represent the cavern inside boundary after the first, second, third, fourth, and fifth drawdown leach, respectively.

As the last step, the Genesis file **bc018_6400.g0** is combined to 106 combined Genesis files above. The inner cavern slice volume in the lower salt layer (Element Block 186400) is assigned to the salt block in the entire model as Element Block 1018. The first through 6th skin volumes in the lower salt layer (Element Block 186401, 186402, 186403, 186404, 186405,and 186406) are combined to Element Block 1018. The node set on the bottom of the lower salt block (Nodeset 180003, GJOIN ID 1) is redefined as Nodeset 3018 which represents the bottom boundary of BC-18 cavern column.

File 69: bc018.gjn

```
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_500.g0
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_660.g0
comb
1.00E-02
no
blocks
id 1 2018
id 8 3018
combine 2018 180501
combine 2018 180502
combine 2018 180503
combine 2018 180504
combine 2018 180505
combine 2018 180506
combine 3018 180661
combine 3018 180662
combine 3018 180663
combine 3018 180664
combine 3018 180665
combine 3018 180666
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_680.g0
comb
1.00E-02
no
blocks
id 3 8018
combine 8018 180681
combine 8018 180682
combine 8018 180683
combine 8018 180684
combine 8018 180685
combine 8018 180686
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_2140.g0
comb
1.00E-02
no
blocks
id 4 1018
combine 1018 182141
combine 1018 182142
combine 1018 182143
combine 1018 182144
combine 1018 182145
combine 1018 182146
up

(To be continued)
```

```
add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_2160.g0
comb
1.00E-02
no
blocks
id 5 101807
id 6 101817
id 7 101827
id 8 101837
id 9 101847
id 10 101857
id 11 101867
up
sset
id 1 180
id 2 181
id 3 182
id 4 183
id 5 184
id 6 185
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_2180.g0
comb
1.00E-02
no
blocks
id 12 10180
id 13 10181
id 14 10182
id 15 10183
id 16 10184
id 17 10185
id 18 10186
up
sset
combine 180 182180
combine 181 182181
combine 182 182182
combine 183 182183
combine 184 182184
combine 185 182185
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_2200.g0
comb
1.00E-02
no
blocks
combine 10180 182200
combine 10181 182201
combine 10182 182202
combine 10183 182203
combine 10184 182204
combine 10185 182205
combine 10186 182206
up
sset
combine 180 182200
combine 181 182201
combine 182 182202
combine 183 182203
combine 184 182204
combine 185 182205
up

.
.
.
(To be continued)
```

```
add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_4160.g0
comb
1.00E-02
no
blocks
combine 10180 184160
combine 10181 184161
combine 10182 184162
combine 10183 184163
combine 10184 184164
combine 10185 184165
combine 10186 184166
up
sset
combine 180 184160
combine 181 184161
combine 182 184162
combine 183 184163
combine 184 184164
combine 185 184165
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_4180.g0
comb
1.00E-02
no
blocks
id 19 101809
id 20 101819
id 21 101829
id 22 101839
id 23 101849
id 24 101859
id 25 101869
up
sset
combine 180 184180
combine 181 184181
combine 182 184182
combine 183 184183
combine 184 184184
combine 185 184185
up

add
/fscratch/bypark/BC_sonar/mesh/bc018/bc018_6400.g0
comb
1.00E-02
no
blocks
combine 1018 186400
combine 1018 186401
combine 1018 186402
combine 1018 186403
combine 1018 186404
combine 1018 186405
combine 1018 186406
up
nset
id 1 3018
up

finish
/fscratch/bypark/BC_sonar/mesh/bc018g1/bc018.g1
```

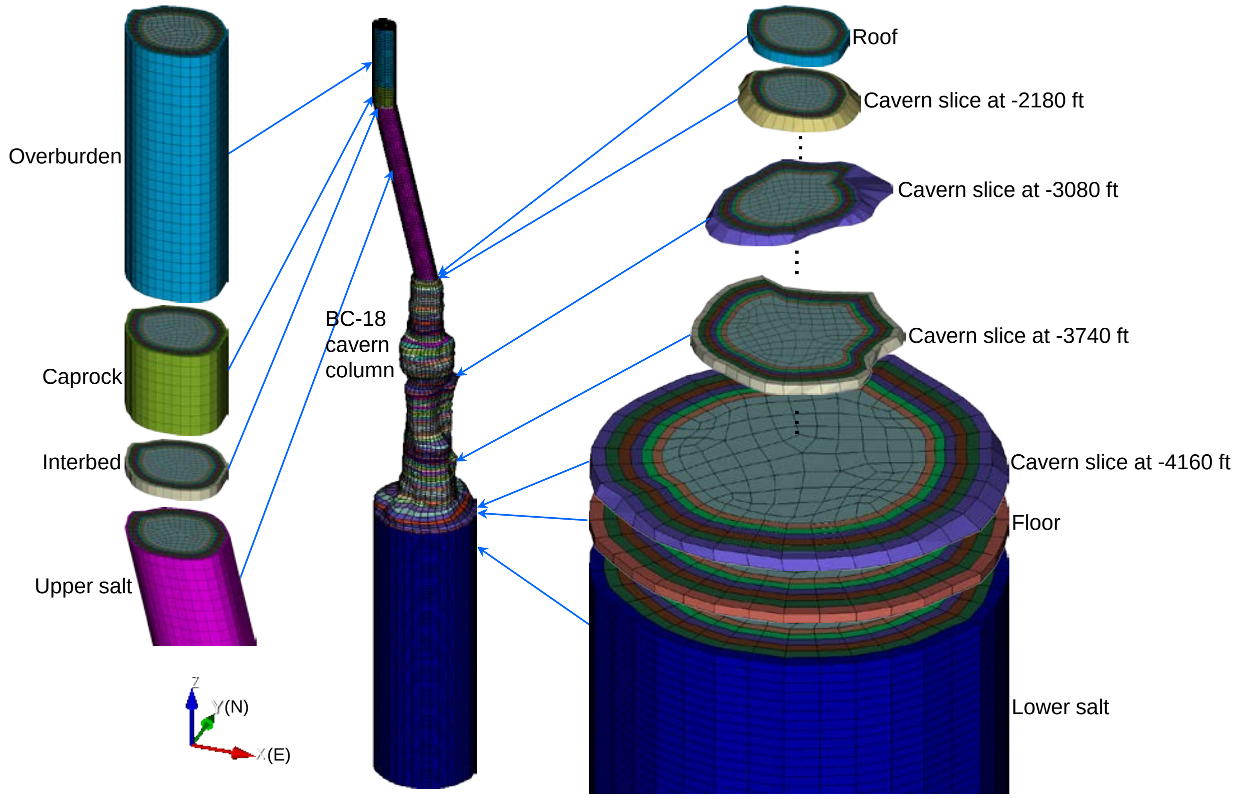


Figure 68: BC-18 cavern column

6.5. Dome

The overall procedure to create the meshed dome was described in Section 4.2.3. The detailed steps will be described in this section.

6.5.1. Data conversion

Figure 69 shows the seismic image, resampled nodes and trimmed vertices of BC-dome. Each node has X-, Y-, and Z- coordinates. The node coordinate data are converted into the vertices data with the Cubit input format through MS Excel manipulation in the similar manner in Section 6.1.1.

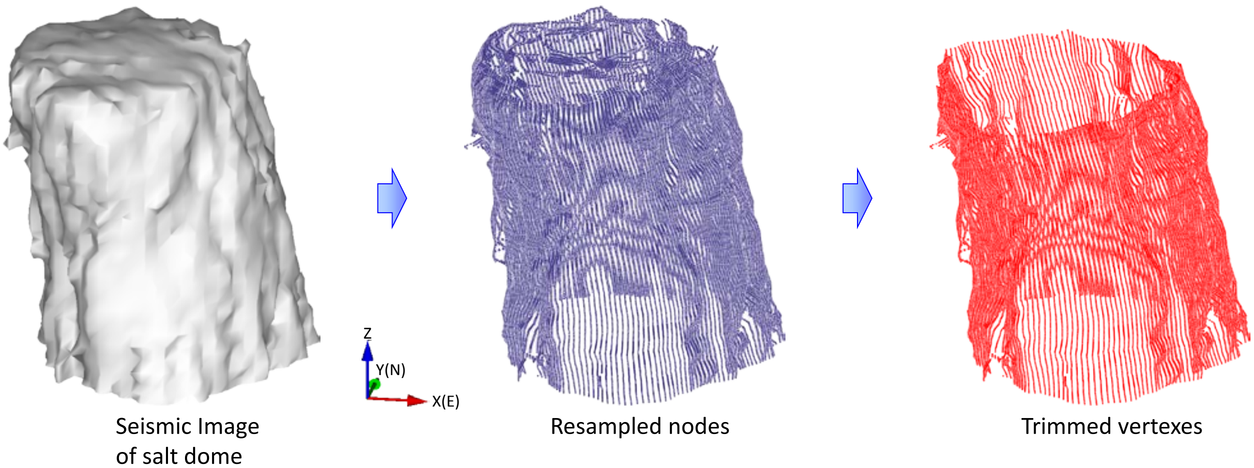


Figure 69: Seismic image, resampled nodes, and trimmed vertices of Bayou Choctaw salt dome

6.5.2. Create dome slice blocks

File 70 shows the Cubit batch run script to create dome slice blocks. These command scripts are executing on the Command Prompt Window as show Figure 17. As the first step, the sub-Cubit journal files and the vertex journal files are copied to the temporary directory of `C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\`. As the next step,. the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou_dome` and then Cubit batch commands are executed.

In the file name of **`bot_0500_surface.jou`** (File 71), **`bot_0500`** indicates the bottom elevation of the slice block is -500 ft which is the bottom elevation of the overburden layer. **`_surface`** indicates the surface block which top elevation is 0 ft.

In the file name of **`bot_0640.jou`** (File 72), **`bot_0640`** indicates the bottom elevation of the block is -640 ft which is the bottom elevation of the roof block of BC-4. The roof of BC-4 intrudes the caprock layer. Every dome slice block will be punched by 26 cavern columns. BC-4 cavern column is separated at -640 ft in the caprock layer because the cavern roof elevation is -640 ft. Therefore, the dome slice block in the caprock layer needs to be separated at -640 ft.

In the file name of **`bot_0660.jou`** (File 73), **`bot_0660`** indicates the bottom elevation of the block is -660 ft which is the bottom elevation of the caprock.

In the file name of **`bot_0680.jou`** (File 74), **`bot_0680`** indicates the bottom elevation of the block is -680 ft which is the bottom elevation of the interbed between the caprock and salt.

In the file name of **`bot_2760.jou`** (File 75), **`bot_2760`** indicates the bottom elevation of the block is -2760 ft which is the bottom elevation of the base salt dome block.

The bottom elevation of the floor block of BC-27 is -6300 ft. Therefore, the dome slice blocks with 20 ft thickness are created downward at every 20 ft elevation from -640 ft to -6300 ft.

In the file name of **`bot_6400`** (File 76) indicates the bottom elevation of the block is -6400 ft which is the bottom elevation of the salt dome as the bottom of the model.

As the last step in File 70, the sub-Cubit journal files and vertex journal files are deleted, after the creation of 286 slice blocks for the salt dome. Every dome slice block will be punched by 26 cavern columns.

File 70: Cubit batch run script to create dome slice blocks

```
copy C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\
copy C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\
cd C:\Sandia.dat\SPR\play_jou_dome
Cubit –batch –nographics –noecho bc_0500_surface.jou
Cubit –batch –nographics –noecho bc_0640.jou
Cubit –batch –nographics –noecho bc_0660.jou
Cubit –batch –nographics –noecho bc_0680.jou
Cubit –batch –nographics –noecho bc_0700.jou
Cubit –batch –nographics –noecho bc_0720.jou
Cubit –batch –nographics –noecho bc_0740.jou
Cubit –batch –nographics –noecho bc_0760.jou
Cubit –batch –nographics –noecho bc_0780.jou
Cubit –batch –nographics –noecho bc_0800.jou
Cubit –batch –nographics –noecho bc_0820.jou
Cubit –batch –nographics –noecho bc_0840.jou
Cubit –batch –nographics –noecho bc_0860.jou
Cubit –batch –nographics –noecho bc_0880.jou
Cubit –batch –nographics –noecho bc_0900.jou
Cubit –batch –nographics –noecho bc_0920.jou
.
.
.
Cubit –batch –nographics –noecho bc_6080.jou
Cubit –batch –nographics –noecho bc_6100.jou
Cubit –batch –nographics –noecho bc_6120.jou
Cubit –batch –nographics –noecho bc_6140.jou
Cubit –batch –nographics –noecho bc_6160.jou
Cubit –batch –nographics –noecho bc_6180.jou
Cubit –batch –nographics –noecho bc_6200.jou
Cubit –batch –nographics –noecho bc_6220.jou
Cubit –batch –nographics –noecho bc_6240.jou
Cubit –batch –nographics –noecho bc_6260.jou
Cubit –batch –nographics –noecho bc_6280.jou
Cubit –batch –nographics –noecho bc_6300.jou
Cubit –batch –nographics –noecho bc_6400.jou
del C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\*.*
y
```

File 71: bot_0500_surface.jou

```
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_0500.jou")}
# Create Volume====================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 72: bot_0640.jou

```
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_0640.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 73: bot_0660.jou

```
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_0660.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 74: bot_0680.jou

```
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_0680.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 75: bot_2760.jou

```
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_2760.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 76: bot_6400.jou

```
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\vtx_6400.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\create_vol.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\temp_sub\save.jou")}
#
exit
```

File 77 shows the Cubit input journal file to create the vertices for the dome slice block in the overburden layer. The elevations of the top and bottom of the block are zero ft and -500 ft, respectively. The dome perimeter consists of 180 vertices with approximately 80 ft intervals. To create the interface between the dome and surrounding rock, one onion skin with approximately 40 ft thickness is considered as shown Figure 70. The coordinate values of the outer perimeter vertices (`Drawdown 1`) in File 77 are calculated using Eq. (4) with the following L_1:

$$L_1 = L_0 + 40 \tag{5}$$

File 77: vtx_0500.jou

```
# Top elevation       : {TELE=       0       }ft
# Bottom elevation    : {BELE=       -500    }ft
# Cavern ID    : {CID=999*10000}
# Base ID of block,sideset,etc.      : {TID=CID-TELE}
# Base ID of block,sideset,etc.      : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=180}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  1064.03       -0.09         0
create vertex  1079.95       68.49         0
create vertex  1044.00       134.73        0
.
.                                                       180 lines     Inner perimeter
.
create vertex  923.69        -190.08       0
create vertex  967.19        -129.53       0
create vertex  1019.07       -66.54        0
### Drawdown 1 ----------------------------------                                  Top
create vertex  1104.03       -0.27         0
create vertex  1119.93       69.71         0
create vertex  1083.91       137.33        0
.
.                                                                     Outer perimeter
.
create vertex  963.45        -194.46       0
create vertex  1007.08       -132.52       0
create vertex  1059.04       -68.13        0
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  1064.03       -0.09         -500
create vertex  1079.95       68.49         -500
create vertex  1044.00       134.73        -500
.
.                                                                     Inner perimeter
.
create vertex  923.69        -190.08       -500
create vertex  967.19        -129.53       -500
create vertex  1019.07       -66.54        -500
### Drawdown 1 ----------------------------------                                  Bottom
create vertex  1104.03       -0.27         -500
create vertex  1119.93       69.71         -500
create vertex  1083.91       137.33        -500
.
.                                                                     Outer perimeter
.
create vertex  963.45        -194.46       -500
create vertex  1007.08       -132.52       -500
create vertex  1059.04       -68.13        -500
```

`create_vol.jou` (File 78) is used to create the dome slice volume in the overburden layer. Error messages will be recorded into `bc_dome_0500.err` and `bc_dome_0500.log` in the following directory:

```
C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\err\
C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\log\
```

These scripts make us easy to check when, where, and why an error occurs during Cubit execution. After a series of Cubit batch runs completes (File 70), 286 slice blocks are created. We can check easily which volume the error occurs at among 286 meshed slice blocks created from 286 batch runs.

In Cubit, a volume consists of surfaces, and a surface consists of curves, and a curve consists of vertices. One curve is created with two vertices. The top and bottom of inner and outer perimeters of the dome slice as shown in Figure 70 consist of 180 curves each created by `create curve vertex`. Two surfaces on top and bottom of the column are created with 180 curves through `create surface`. Two volumes are created by `create volume loft surface` through matching the vertices on top and bottom surfaces one by one using `match vertex`. Two volumes are overlapped. To separate two volumes, the outside volume is cut by the surface of the inside volume through `webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}`, and then a dome slice volume and onion skin volume enclosing the dome slice volume are created. The duplicated dome slice volume are deleted using `delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}`. During creating volumes, unexpected vertices are created occasionally on curves which connect the top vertices to the bottom vertices. The unexpected vertices create unexpected mesh lines which cause skew mesh shape, so they have to be removed through `simplify curve all except curve {TVTX0} to {TNVTX}`. To remove the duplicated geometries such vertex, curve, surface, etc., all geometries are merged through `merge all`. The unnecessary surfaces, which were created during the process, are removed using `delete body 1 to {TNSB}`.

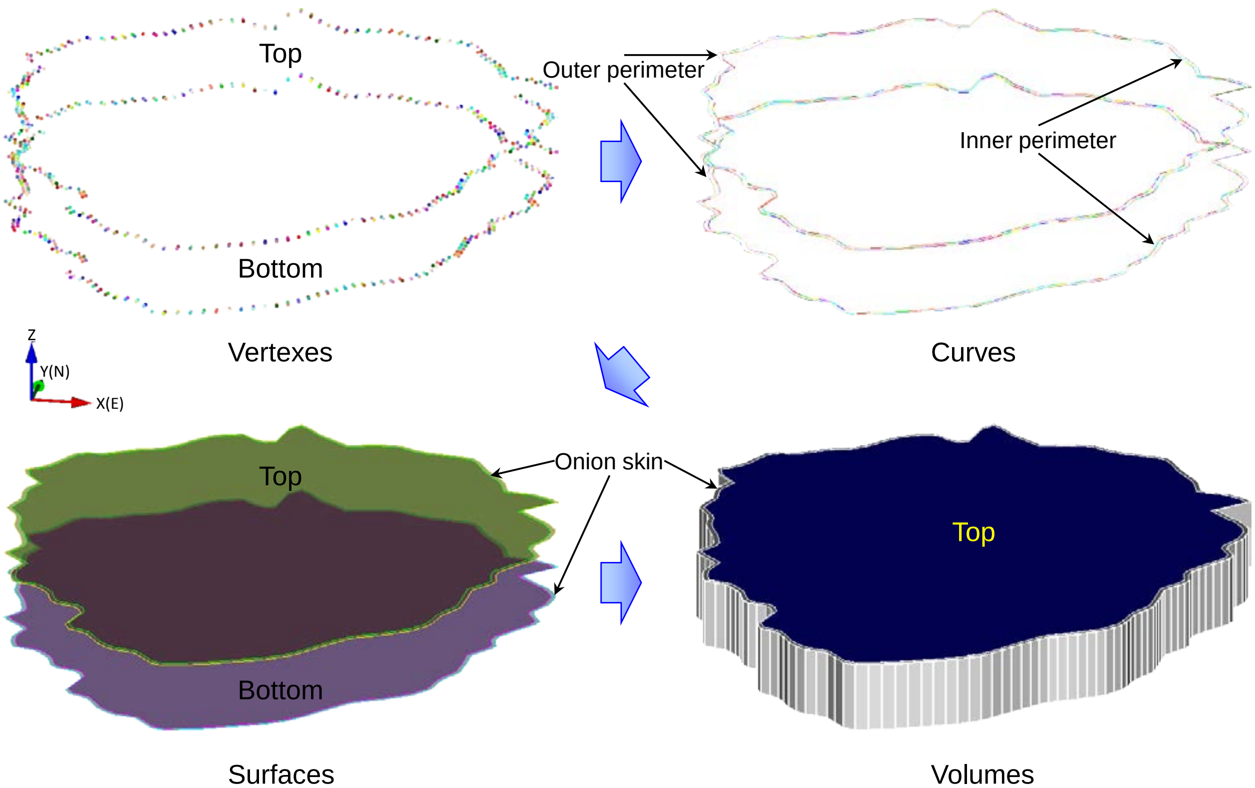


Figure 70: Vertices, curves, surfaces, and volumes of dome slice block in overburden layer

File 78: create_vol.jou

```
Logging                          Errors                          on                          file
{Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\err\bc_dome_"//tostring(-BELE)//".err")}
Set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\log\bc_dome_"//tostring(-
BELE)//".log")}
# Create Curve ==================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Dome) -----------------
create curve vertex {TVTX0=VI0*NVTX+1} {TVTX0+1}
create curve vertex {TVTX0+1} {TVTX0+2}
create curve vertex {TVTX0+2} {TVTX0+3}
.
.                                                      180 lines     Inner perimeter
.
create curve vertex {TVTX0+177} {TVTX0+178}
create curve vertex {TVTX0+178} {TVTX0+179}
create curve vertex {TVTX0+179} {TVTX0}
### Drawdown 1 ----------------------------------                         Top
create curve vertex {TVTX1=VI1*NVTX+1} {TVTX1+1}
create curve vertex {TVTX1+1} {TVTX1+2}
create curve vertex {TVTX1+2} {TVTX1+3}
.
.                                                                    Outer perimeter
.
create curve vertex {TVTX1+177} {TVTX1+178}
create curve vertex {TVTX1+178} {TVTX1+179}
create curve vertex {TVTX1+179} {TVTX1}
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Dome) -----------------
create curve vertex {BVTX0=(NVOL+VI0)*NVTX+1} {BVTX0+1}
create curve vertex {BVTX0+1} {BVTX0+2}
create curve vertex {BVTX0+2} {BVTX0+3}
.
.                                                                    Inner perimeter
.
create curve vertex {BVTX0+177} {BVTX0+178}
create curve vertex {BVTX0+178} {BVTX0+179}
create curve vertex {BVTX0+179} {BVTX0}
### Drawdown 1 ----------------------------------                         Bottom
create curve vertex {BVTX1=(NVOL+VI1)*NVTX+1} {BVTX1+1}
create curve vertex {BVTX1+1} {BVTX1+2}
create curve vertex {BVTX1+2} {BVTX1+3}
.
.                                                                    Outer perimeter
.
create curve vertex {BVTX1+177} {BVTX1+178}
create curve vertex {BVTX1+178} {BVTX1+179}
create curve vertex {BVTX1+179} {BVTX1}
# Create Surface ================================================
Create surface curve {TVTX0} to {TVTX1-1}
Create surface curve {TVTX1} to {BVTX0-1}
Create surface curve {BVTX0} to {BVTX1-1}
Create surface curve {BVTX1} to {TNVTX}
```

(To be continued)

```
# Create Volume ====================================================
### Drawdown 0 (Initial Dome) -----------------
create volume loft surface {TSI0} {BSI0} \
match vertex {TVTX0} {BVTX0} \
match vertex {TVTX0+1} {BVTX0+1} \
match vertex {TVTX0+2} {BVTX0+2} \
.
.                                                     180 lines     cavern column volume
.
match vertex {TVTX0+177} {BVTX0+177} \
match vertex {TVTX0+178} {BVTX0+178} \
match vertex {TVTX0+179} {BVTX0+179}
### Drawdown 1 -----------------------------------
create volume loft surface {TSI1} {BSI1} \
match vertex {TVTX1} {BVTX1} \
match vertex {TVTX1+1} {BVTX1+1} \
match vertex {TVTX1+2} {BVTX1+2} \
.
.                                                                   Skin column volume
.
match vertex {TVTX1+177} {BVTX1+177} \
match vertex {TVTX1+178} {BVTX1+178} \
match vertex {TVTX1+179} {BVTX1+179}
## Create onion skin volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~
webcut body {TNSB+VI1+1} tool body {TNSB+VI0+1}
#
delete body {TNSB+NDL+2} to {TNSB+2*NDL+1}
### remove the vertices on the curves BEtween the top and bottom
simplify curve all except curve{TVTX0}to {TNVTX}
merge all  # to remove unnecessary vertices
delete body 1 to {TNSB}
```

File 79 shows the Cubit input journal file to create the vertices for the base dome slice block. The elevations of the top and bottom of the block are -2740 ft and -2760 ft, respectively. The dome perimeter consists of 180 vertices with approximately 80 ft intervals. To create the interface between the dome and surrounding rock, one onion skin with approximately 40 ft thickness is considered as shown Figure 71.

The same **`create_vol.jou`** (File 78) is used to create the base dome slice volume. Error messages will be recorded into **`bc_dome_2760.err`** and **`bc_dome_2760.log`** in the following directory:

```
C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\err\
C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\log\
```

File 79: vtx_2760.jou

```
# Top elevation       : {TELE=       -2740   }ft
# Bottom elevation    : {BELE=       -2760   }ft
# Cavern ID    : {CID=999*10000}
# Base ID of block,sideset,etc.       : {TID=CID-TELE}
# Base ID of block,sideset,etc.       : {BID=CID-BELE}
# !!! Note: number of Vertices has to be even number
# number of vertices           : {NVTX=180}
# number of drowdown leaches  : {NDL=1}
# number of volumes            : {NVOL=NDL+1}
# total number of vertices in one layer     : {TNVTX=NVTX*NVOL*2}
# total number of sheet bodies in one layer: {TNSB=NVOL*2}
# original cavern volume ID    : {VI0=0}
# 1st drawdown skin volume ID : {VI1=1}
# original cavern volume top surface ID   : {TSI0=1}
# 1st drawdown skin volume top surface ID: {TSI1=2}
# original cavern volume bot surface ID   : {BSI0=TSI0+NVOL}
# 1st drawdown skin volume bot surface ID: {BSI1=TSI1+NVOL}
# created zro drawdown cavern volume   : {VDL0=TNSB+1}
# created 1st drawdown skin volume     : {VDL1=TNSB+2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
# Create vertex =====================================================
## Top ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  1476.03        121.36         -2740
create vertex  1517.18        187.82         -2740
create vertex  1608.81        260.85         -2740
.
.                                                     180 lines    Inner perimeter
.                                                                                      Top
create vertex  1571.88        -84.43         -2740
create vertex  1500.51        -10.56         -2740
create vertex  1444.61        57.43          -2740
### Drawdown 1 ----------------------------------
create vertex  1516.03        121.31         -2740
create vertex  1557.16        189.17         -2740
create vertex  1648.71        263.60         -2740
.
.                                                                  Outer perimeter
.
create vertex  1611.66        -88.66         -2740
create vertex  1540.41        -13.41         -2740
create vertex  1484.58        55.98          -2740
## Bottom ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Drawdown 0 (Initial Cavern) -----------------
create vertex  1483.52        122.63         -2760
create vertex  1517.15        188.88         -2760
create vertex  1609.86        261.77         -2760
.
.                                                                  Inner perimeter
.                                                                                      Bottom
create vertex  1583.96        -83.78         -2760
create vertex  1506.55        -9.28          -2760
create vertex  1450.13        58.73          -2760
### Drawdown 1 ----------------------------------
create vertex  1523.52        122.59         -2760
create vertex  1557.13        190.23         -2760
create vertex  1649.76        264.52         -2760
.
.                                                                  Outer perimeter
.
create vertex  1623.73        -88.01         -2760
create vertex  1546.45        -12.12         -2760
create vertex  1490.11        57.28          -2760
```

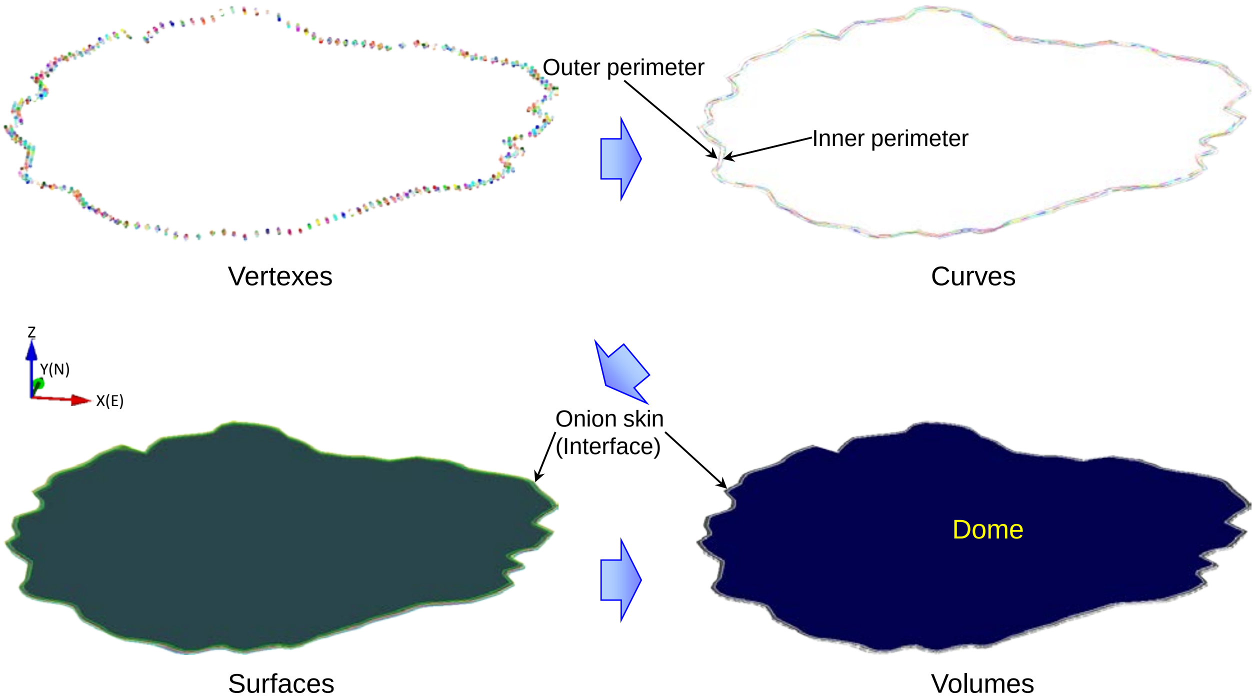


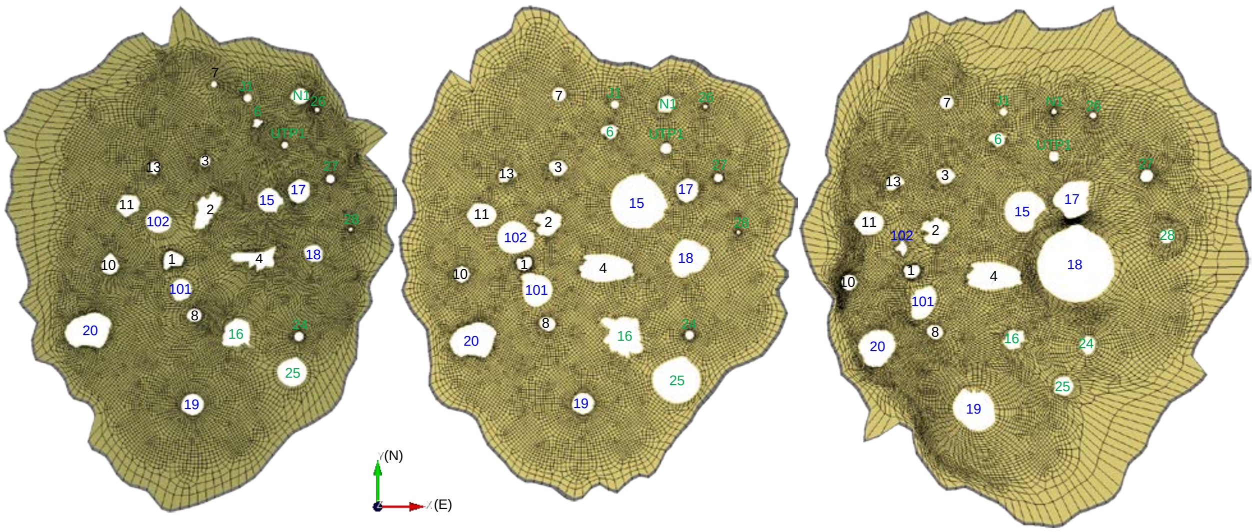
Figure 71: Vertices, curves, surfaces, and volumes of base dome slice block at -2760 ft

6.5.3. Base dome slice block

The dome area changes with depth. Each cavern column cross-sections also changes with depth. Therefore, each element shape is also changing with depth while the number of elements in the area should be kept constant because every element is hexahedral, i.e. the elements on the surface should be translated parallel to the bottom surface of the model with maintaining the same number of elements. To obtain better overall mesh quality of the entire dome, a base block is selected, and then the element shapes on the top of the base block will be translated upward to the surface; the element shape on the bottom of the base block will be translated downward to the bottom of the dome.

The base block needs to be selected to optimize the mesh quality. Figure 72 shows the area changes of the dome, from which the cavern column areas are subtracted, at the surface (0 ft), -2760 ft, and the model bottom (-6400 ft). The concerning locations are the webs between BC-20 and the dome edge; BC-25 and the dome edge; BC-15 and BC-17; BC-1 and BC-102; BC-1 and BC-101. According to the functionality of Cubit, the local area, where the web size is getting smaller, could make a skew element, i.e. a negative shape element is created. For example, the local areas between BC-17 and BC-18; BC-10 and the dome edge at the bottom section in Figure 72are narrower than that at -2760 ft, i.e. the element density is getting higher. Skew elements could be created at these local areas. To reduce this kind of area as little as possible, the base block needs to be selected. If the bottom cross-section is selected as a base block, the web between BC-25 and the dome edge should make negative shape elements at -2760 ft.

The concerning caverns in this model are SPR caverns such as BC-15, BC-17, BC-18, BC-19, BC-20, BC-101, and BC-102. To maintain the accuracy of the result, the element shapes around the SPR cavers need to be better than others. Meshing starts at the base block, i.e. the quality of elements at the base block is the best. Therefore, it will be better that the base block is selected around the SPR cavern elevation. Considering these conditions, the block which bottom is -2760 ft is selected as the base block.



Surface (0 ft) Base (-2760 ft) Bottom (-6400 ft)

Figure 72: Dome and cavern column cross-sections at surface, -2760 ft, and -6400 ft

File 80 shows the Cubit batch run script for the base block mesh. These command scripts are executing on the Command Prompt Window as show Figure 17. As the first step, the sub-Cubit journal files and the vertex journal files are moved to the temporary directories of `C:\Sandia.dat\SPR\temp_sub\` and `C:\Sandia.dat\SPR\temp_vtx\`, respectively. As the next step, the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou` and then Cubit batch commands are executed. As the last step, the sub-Cubit journal files and the vertex journal files are moved to the original directories.

`bot_2760_base.jou` (File 81) is the Cubit play scripts to punch cavern column holes into the base dome slice block in Figure 71 and then create mesh in the punched block. **`vtx_2760.jou`** (File 82) is the Cubit play scripts to execute **`define_parameters.jou`** (File 83) and **`import_2720.jou`** (File 84).

Figure 73 shows the imported base dome slice block and 26 cavern columns through File 84. The caverns are located above, at, and below the base block as follows:

- 10 Caverns above the base block: BC-1, BC-2, BC-3, BC-4, BC-6, BC-7, BC-8, BC-10, BC-11, and BC-13
- 10 caverns at the base block: BC-15, BC16, BC-17, BC-18, BC-25, BC-26, BC-N1, BC-UTP, BC-101, and BC-102
- 6 caverns below the base block: BC-19, BC-20, BC-24, BC-27, BC-28, and BC-J1
- The outmost skin volume of each cavern is imported to punch the holes into the base block.

The upper salt skin volumes of the caverns above the base block, cavern slice skin volumes at the base block, and lower salt skin volumes of the caverns below the base block are imported into the base block.

The Cubit sub-journal to import the cavern columns (File 84) are made based on the top and bottom elevations of the caverns listed in Table 5.

The base dome slice block is punched by “`webcut`” command script in File 85 as shown Figure 73 (left). ″`simplify curve`” command was described in Sections 6.1.7 and 6.4.7.

As described in Section 6.3, BC-7 is simplified by cylinder. To mesh the base block on the cylinder perimeter curve, the curve is divided by 18 intervals through `curve 27802 interval {NIP}`. File 86 shows the groups defined for meshing the base block.

File 87 shows the Cubit command scripts to create mesh in the punched volume in Figure 74 (left). The top surface of inner slice volume is meshed using the following scripts:

```
surface in sdl0t vertex in vdl0t type side
surface in sdl0t interval 1
mesh surface in sdl0t
```

The key methodologies in the mesh process were described in Sections 6.1.3.2 and 6.2.3 including `type side`. To create mesh lines at vertices at which mesh lines are not created, the following script is executed as mentioned in Section 6.2.3:

```
pillow face in surface in sdl0t
```

To improve the mesh quality on the top surface of the inner volume of dome slice block, “smoothing” steps are conducted until no smoothing is needed with the following scripts:

```
smooth surface in sdl0t
surface in tsurf smooth scheme cond
smooth surface in sdl0t
smooth surface in sdl0t
smooth surface in sdl0t
smooth surface in sdl0t
```

The top surface of the interface between dome and surrounding rock (onion skin of dome) is meshed through the following scripts:

```
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1
mesh surface in sdl1t
```

To avoid creating skewed mesh, the option `scheme hole rad_intervals 1` is applied as mentioned in Section 6.2.3.

The vertical curves on the volume are divided by 20ft then one element level is created because the thickness of the base slice block is 20 ft through the following scripts:

```
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
mesh volume {VLSC} {VDL1}
```

Then, the base dome slice block (dome and interface volumes) is meshed entirely with the meshed horizontal section and vertical curves. The dome and interface volumes are defined as `Element Blocks 9992760` and `9992760`, respectively, as described in Section 3.5.1.

To improve the mesh quality on the bottom surface of the dome slice block, "smoothing" steps are conducted until no smoothing is needed with the following scripts:

```
#### Smoothing ------------------------
smooth surface in sdl0b
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b            # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.596e-02 (90249335)
```

Finally, the meshed dome slick block (Figure 74, right) is saved as Cubit file and Genesis file, and the related information files are saved as ASCII data through File 88.

File 80: cubit_batch_run_base.txt

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho -nojournal bot_2760_base.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\
```

File 81: bot_2760_base.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2760.jou")}
# Create Curve =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_base.jou")}
# Save =============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 82: vtx_2760.jou

```
# Top elevation              : {TELE=       -2740   }ft
# Bottom elevation     : {BELE=       -2760   }ft
# Define parameters ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
# Import cub =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\import_2720.jou")}
```

File 83: define_parameters.jou

```
# Define Parameters ================================================
# Dome ID      : {CID=999*10000}
# Base ID of block     sideset etc.   : {TID=CID-TELE}
# Base ID of block     sideset etc.   : {BID=CID-BELE}
# original dome volume ID     : {VI0=0}
# 1st skin volume ID          : {VI1=1}
# number of skin       : {NDL=1}
# number of volumes    : {NVOL=NDL+1}
# number of dome skins: {NCS=26}
# created zro drawdown dome volume    : {VDL0=2*NVOL+1}
# created 1st drawdown skin volume    : {VDL1=2*NVOL+2}
#
# bc001 skin volume    : {V001=2*VDL1}
# bc002 skin volume    : {V002=V001+VDL1}
# bc003 skin volume    : {V003=V002+VDL1}
# bc004 skin volume    : {V004=V003+VDL1}
# bc006 skin volume    : {V006=V004+VDL1}
# bc007 skin volume    : {V007=V006+22}      # imported volume ID=22 for BC-7
# bc008 skin volume    : {V008=V007+VDL1}
# bc010 skin volume    : {V010=V008+VDL1}
# bc011 skin volume    : {V011=V010+VDL1}
# bc013 skin volume    : {V013=V011+VDL1}
# bc015 skin volume    : {V015=V013+VDL1*2+3}
# bc016 skin volume    : {V016=V015+VDL1}
# bc017 skin volume    : {V017=V016+VDL1*2+3}
# bc018 skin volume    : {V018=V017+VDL1*3+3}
# bc019 skin volume    : {V019=V018+VDL1*3+3}
# bc020 skin volume    : {V020=V019+VDL1}
# bc024 skin volume    : {V024=V020+VDL1}
# bc025 skin volume    : {V025=V024+VDL1}
# bc026 skin volume    : {V026=V025+VDL1}
# bc027 skin volume    : {V027=V026+VDL1}
# bc028 skin volume    : {V028=V027+VDL1}
# bc031 skin volume    : {V031=V028+VDL1}
# bc032 skin volume    : {V032=V031+VDL1}
# bc033 skin volume    : {V033=V032+VDL1}
# bc101 skin volume    : {V101=V033+VDL1*3+3}
# bc102 skin volume    : {V102=V101+VDL1*3+3}
# last  skin volume    : {VLST=V102}
# last created volume   : {VLSC=VLST+NCS*2}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
#
Logging  Errors  on  file  {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\err\dome_"//tostring(-
BELE)//".err")}
Set   logging   on   file   {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\log\dome_"//tostring(-
BELE)//".log")}
```

File 84: import_2720.jou

```
# Import cub ========================================================
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\cub\bc_dome_"//tostring(-BELE)//".cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc002\cub\bc002_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc003\cub\bc003_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\cub\bc004_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc006\cub\bc006_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc008\cub\bc008_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc010\cub\bc010_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc011\cub\bc011_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc013\cub\bc013_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc015\cub\bc015_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc016\cub\bc016_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc017\cub\bc017_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc019\cub\bc019_"//tostring(2960)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc020\cub\bc020_"//tostring(3740)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc024\cub\bc024_"//tostring(3080)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc025\cub\bc025_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc026\cub\bc026_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc027\cub\bc027_"//tostring(4680)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc028\cub\bc028_"//tostring(4680)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc031_J1\cub\bc031_"//tostring(2840)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc032_N1\cub\bc032_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc033_UTP\cub\bc033_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc101\cub\bc101_"//tostring(-BELE)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc102\cub\bc102_"//tostring(-BELE)//"_skn.cub")}
```

File 85: create_vol_base.jou

```
zoom reset
# Webcut ==========================================================
webcut volume {VDL0} tool volume {V001}
delete volume {VDL0} {V001} {VLST+1}
webcut volume {VLST+ 2} tool volume {V002}
delete volume {V002} {VLST+ 2} {VLST+ 3}
webcut volume {VLST+ 4} tool volume {V003}
delete volume {V003} {VLST+ 4} {VLST+ 5}
webcut volume {VLST+ 6} tool volume {V004}
delete volume {V004} {VLST+ 6} {VLST+ 7}
webcut volume {VLST+ 8} tool volume {V006}
delete volume {V006} {VLST+ 8} {VLST+ 9}
webcut volume {VLST+10} tool volume {V007}
delete volume {V007} {VLST+10} {VLST+11}
webcut volume {VLST+12} tool volume {V008}
delete volume {V008} {VLST+12} {VLST+13}
webcut volume {VLST+14} tool volume {V010}
delete volume {V010} {VLST+14} {VLST+15}
webcut volume {VLST+16} tool volume {V011}
delete volume {V011} {VLST+16} {VLST+17}
webcut volume {VLST+18} tool volume {V013}
delete volume {V013} {VLST+18} {VLST+19}
webcut volume {VLST+20} tool volume {V015}
delete volume {V015} {VLST+20} {VLST+21}
webcut volume {VLST+22} tool volume {V016}
delete volume {V016} {VLST+22} {VLST+23}
webcut volume {VLST+24} tool volume {V017}
delete volume {V017} {VLST+24} {VLST+25}
webcut volume {VLST+26} tool volume {V018}
delete volume {V018} {VLST+26} {VLST+27}
webcut volume {VLST+28} tool volume {V019}
delete volume {V019} {VLST+28} {VLST+29}
webcut volume {VLST+30} tool volume {V020}
delete volume {V020} {VLST+30} {VLST+31}
webcut volume {VLST+32} tool volume {V024}
delete volume {V024} {VLST+32} {VLST+33}
webcut volume {VLST+34} tool volume {V025}
delete volume {V025} {VLST+34} {VLST+35}
webcut volume {VLST+36} tool volume {V026}
delete volume {V026} {VLST+36} {VLST+37}
webcut volume {VLST+38} tool volume {V027}
delete volume {V027} {VLST+38} {VLST+39}
webcut volume {VLST+40} tool volume {V028}
delete volume {V028} {VLST+40} {VLST+41}
webcut volume {VLST+42} tool volume {V031}
delete volume {V031} {VLST+42} {VLST+43}
webcut volume {VLST+44} tool volume {V032}
delete volume {V032} {VLST+44} {VLST+45}
webcut volume {VLST+46} tool volume {V033}
delete volume {V033} {VLST+46} {VLST+47}
webcut volume {VLST+48} tool volume {V101}
delete volume {V101} {VLST+48} {VLST+49}
webcut volume {VLST+50} tool volume {V102}
delete volume {V102} {VLST+50} {VLST+51}
# Define group ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_dome.jou")}
# Remove unexpected vertices =========================================
vertex vis on
simplify curve all except curve      in tsurf bsurf
merge all
vertex vis off
# Number of intervals on perimeter: {NIP=18}
#curve 27802 27803 interval {NIP}
curve 27802 interval {NIP}
```

File 86: define_group_dome.jou

```
## Define group ========================================================
group "tcurv" add curve in volume all with z_coord > {TELE-0.1}
group "bcurv" add curve in volume all with z_coord < {BELE+0.1}
group "tsurf" add surface in volume all with z_coord > {TELE-0.1}
group "bsurf" add surface in volume all with z_coord < {BELE+0.1}
group "msurf" add surface in volume all
group "msurf" remove surface in tsurf
group "msurf" remove surface in bsurf
### Drawdown 0 (Initial Dome) ------------------
#### Vertices on top of the volume
group "vdl0t" add vertex in volume {VLSC} with z_coord > {TELE-0.1}
#### Curves on outside wall of the volume
group "cdl0w" add curve in volume {VLSC}
group "cdl0w" remove curve in tcurv
group "cdl0w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl0t" add surface in volume {VLSC}
group "sdl0t" remove surface in msurf
group "sdl0t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl0w" add surface in volume {VLSC}
group "sdl0w" remove surface in tsurf
group "sdl0w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl0b" add surface in volume {VLSC}
group "sdl0b" remove surface in msurf
group "sdl0b" remove surface in tsurf
### Drawdown 1 ---------------------------------
#### Curves on outside wall of the volume
group "cdl1w" add curve in volume {VDL1}
group "cdl1w" remove curve in volume {VLSC}
group "cdl1w" remove curve in tcurv
group "cdl1w" remove curve in bcurv
#### Surfaces on top of the volume
group "sdl1t" add surface in volume {VDL1}
group "sdl1t" remove surface in msurf
group "sdl1t" remove surface in bsurf
#### Surfaces on outside wall of the volume
group "sdl1w" add surface in volume {VDL1}
group "sdl1w" remove surface in volume {VLSC}
group "sdl1w" remove surface in tsurf
group "sdl1w" remove surface in bsurf
#### Surfaces on bot of the volume
group "sdl1b" add surface in volume {VDL1}
group "sdl1b" remove surface in msurf
group "sdl1b" remove surface in tsurf
### Skin for webcut = {skn=VDL1} ----------------
```

File 87: mesh_base.jou

```
# Mesh ==============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~~
### Dome itself -----------------
surface in sdl0t vertex in vdl0t type side
surface in sdl0t interval 1
mesh surface in sdl0t
#### fix no mesh line at vertices
pillow face in surface in sdl0t
#### Smoothing until no smoothing needed --------
smooth surface in sdl0t
surface in tsurf smooth scheme cond
smooth surface in sdl0t
smooth surface in sdl0t
smooth surface in sdl0t
smooth surface in sdl0t
### Interface between dome and surrounding rock
surface in sdl1t interval 1
surface in sdl1t scheme hole rad_intervals 1 # keep interval 1 to avoid two layer mesh and
skewed mesh
mesh surface in sdl1t
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ---------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
mesh volume {VLSC} {VDL1}
# Define Blocks =====================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
#### Smoothing -----------------------
smooth surface in sdl0b
###Initial minimum scaled jacobian = -0.776479 (Command Prompt, 60 repeats smooth surface)
surface in sdl0b smooth scheme cond # until no smoothing needed
smooth surface in sdl0b             # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0b             # Minimum   (id) 2.596e-02 (90249335)
```

File 88: save_base.jou

```
# Save ==============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_"//tostring(-BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\g0\dome_"//tostring(-BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_abstract_base.txt")} resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//".cub")} overwrite
set logging off
echo on
delete volume all except {skn}
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//"_skn.cub")} overwrite
```

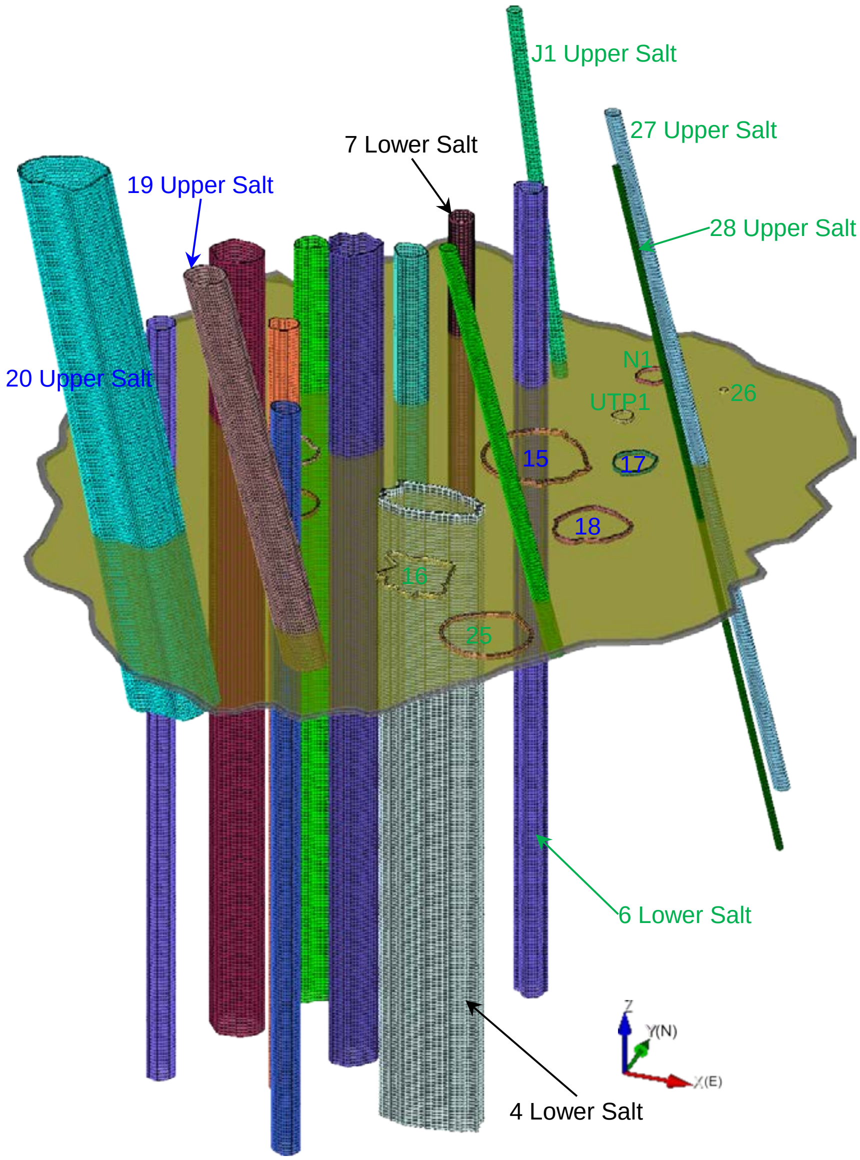


Figure 73: Base dome slice block and cavern columns

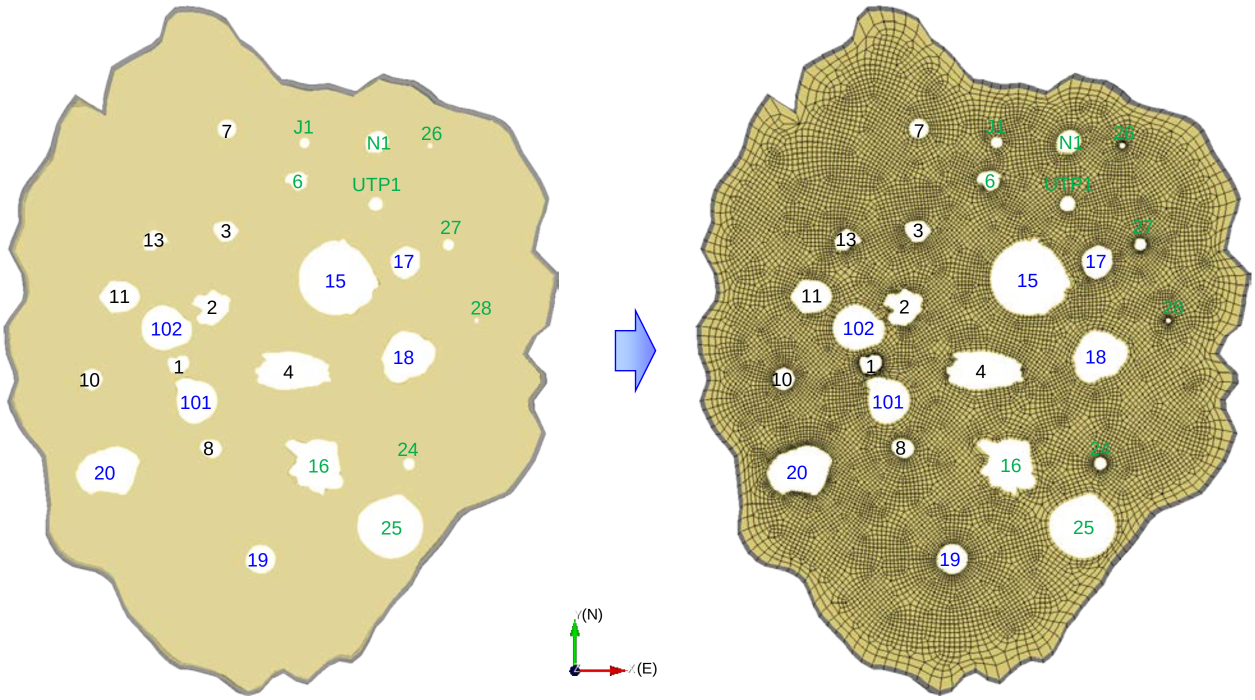


Figure 74: Punched (left) and meshed (right) dome base block

6.5.4. Mesh upward

The mesh on the top of the base slice block is translated upward through every dome slice block over the base slice block. **`cubit_batch_run_up.txt`** (File 89) shows the Cubit play scripts to create meshed blocks which bottom elevations increases from -2740 ft to -640 ft with 20 ft thickness. Continuously, it creates the caprock dome block (-500 ft top and -640 ft bottom elevations) and the overburden dome block (0 ft top and -500 ft bottom elevations). As mentioned in Section 6.2.4, the roof elevation of BC-4 is -640 ft. Therefore, the caprock dome slice block is separated at -640 ft.

Figure 75 shows the steps to create the meshed dome slice block right above the base dome slice block through the play file **`bot_2740_up.jou`** (File 90). **`vtx_2740.jou`** (File 91) defines parameters (**`define_parameters.jou`**, File 83) and imports the cavern columns (**`import_2720.jou`**, File 84). The dome slice block, which bottom elevation is -2740 ft, is punched by the cavern columns through **`create_vol.jou`** (File 92).

The dome slice block is meshed through **`mesh_wall_up.jou`** (File 93). The base dome slice block is imported to be used as the reference mesh block, and two blocks are merged together through the following scripts:

```
# Mesh ==============================================================
### Import reference mesh ------------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE+20)//".cub")}
merge tol 0.05
merge all
```

The mesh on the top of the base dome slice block translates to the bottom of the dome slice block (-2740 ft), and then the block is meshed through the following scripts:

```
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
```

```
mesh volume {VLSC} {VDL1}
```

The imported base dome slice block is deleted. The inner dome slice block is defined as `Element Block 9992740`, the outer dome slice block (interface between dome and surrounding rock) is defined as `Element Block 9992741` through the following scripts:

```
# Delete unnecessaries ============================================
delete block {BID+20} to {BID+20+NDL}
delete volume {VLSC+VDL1} {VLSC*2}
# Define Blocks ===================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
```

"Negative Jacobian Hexahedral Element" is created on the top surface of the inner slice volume. The negative element is improved and to become a positive element as shown Figure 76 through the following scripts:

```
#### Smoothing ------------------------
###Initial minimum scaled jacobian = -0.776479 (Command Prompt, 60 repeats smooth
surface)
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t             # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0t             # Minimum   (id) 2.596e-02 (90249335)
```

As the final step, the meshed block is saved as Cubit file and Genesis file through **`save_up.jou`** (File 94).

These steps are repeated to create the dome slice blocks from -2720 ft to the surface, then 107 dome slice blocks are created above the base dome slice block.

File 89: cubit_batch_run_up.txt

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho -nojournal bot_2740_up.jou
Cubit –batch –nographics –noecho -nojournal bot_2720_up.jou
Cubit –batch –nographics –noecho -nojournal bot_2700_up.jou
Cubit –batch –nographics –noecho -nojournal bot_2680_up.jou
Cubit –batch –nographics –noecho -nojournal bot_2660_up.jou
.
.
.
Cubit –batch –nographics –noecho -nojournal bot_0720_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0700_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0680_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0660_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0640_above_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0500_above_up.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\
```

File 90: bot_2740_up.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2740.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall_up.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_up.jou")}
#
exit
```

File 91: vtx_2740.jou

```
# Top elevation               : {TELE=       -2720   }ft
# Bottom elevation    : {BELE=       -2740   }ft
# Define parameters =================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
# Import cub ========================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\import_2720.jou")}
```

File 92: create_vol.jou

```
zoom reset
# Webcut ============================================================
webcut volume {VDL0} tool volume {V001}
delete volume {VDL0} {V001} {VLST+1}
webcut volume {VLST+ 2} tool volume {V002}
delete volume {V002} {VLST+ 2} {VLST+ 3}
webcut volume {VLST+ 4} tool volume {V003}
delete volume {V003} {VLST+ 4} {VLST+ 5}
webcut volume {VLST+ 6} tool volume {V004}
delete volume {V004} {VLST+ 6} {VLST+ 7}
webcut volume {VLST+ 8} tool volume {V006}
delete volume {V006} {VLST+ 8} {VLST+ 9}
webcut volume {VLST+10} tool volume {V007}
delete volume {V007} {VLST+10} {VLST+11}
webcut volume {VLST+12} tool volume {V008}
delete volume {V008} {VLST+12} {VLST+13}
webcut volume {VLST+14} tool volume {V010}
delete volume {V010} {VLST+14} {VLST+15}
webcut volume {VLST+16} tool volume {V011}
delete volume {V011} {VLST+16} {VLST+17}
webcut volume {VLST+18} tool volume {V013}
delete volume {V013} {VLST+18} {VLST+19}
webcut volume {VLST+20} tool volume {V015}
delete volume {V015} {VLST+20} {VLST+21}
webcut volume {VLST+22} tool volume {V016}
delete volume {V016} {VLST+22} {VLST+23}
webcut volume {VLST+24} tool volume {V017}
delete volume {V017} {VLST+24} {VLST+25}
webcut volume {VLST+26} tool volume {V018}
delete volume {V018} {VLST+26} {VLST+27}
webcut volume {VLST+28} tool volume {V019}
delete volume {V019} {VLST+28} {VLST+29}
webcut volume {VLST+30} tool volume {V020}
delete volume {V020} {VLST+30} {VLST+31}
webcut volume {VLST+32} tool volume {V024}
delete volume {V024} {VLST+32} {VLST+33}
webcut volume {VLST+34} tool volume {V025}
delete volume {V025} {VLST+34} {VLST+35}
webcut volume {VLST+36} tool volume {V026}
delete volume {V026} {VLST+36} {VLST+37}
webcut volume {VLST+38} tool volume {V027}
delete volume {V027} {VLST+38} {VLST+39}
webcut volume {VLST+40} tool volume {V028}
delete volume {V028} {VLST+40} {VLST+41}
webcut volume {VLST+42} tool volume {V031}
delete volume {V031} {VLST+42} {VLST+43}
webcut volume {VLST+44} tool volume {V032}
delete volume {V032} {VLST+44} {VLST+45}
webcut volume {VLST+46} tool volume {V033}
delete volume {V033} {VLST+46} {VLST+47}
webcut volume {VLST+48} tool volume {V101}
delete volume {V101} {VLST+48} {VLST+49}
webcut volume {VLST+50} tool volume {V102}
delete volume {V102} {VLST+50} {VLST+51}
# Define group =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_dome.jou")}
# Remove unexpected vertices =========================================
vertex vis on
simplify curve all except curve      in tsurf bsurf
merge all
vertex vis off
```

File 93: mesh_wall_up.jou

```
# Mesh =============================================================
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE+20)//".cub")}
merge tol 0.05
merge all
### View bottom
graphics mode SmoothShade
view reset
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
mesh volume {VLSC} {VDL1}
# Delete unnecessaries ==============================================
delete block {BID+20} to {BID+20+NDL}
delete volume {VLSC+VDL1} {VLSC*2}
# Define Blocks =====================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
#### Smoothing -----------------------
###Initial minimum scaled jacobian = -0.776479 (Command Prompt, 60 repeats smooth surface)
surface in sdl0t smooth scheme cond # until no smoothing needed
smooth surface in sdl0t            # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0t            # Minimum   (id) 2.596e-02 (90249335)
```

File 94: save_up.jou

```
# Save =============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_"//tostring(-BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\g0\dome_"//tostring(-BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_abstract_up.txt")} resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//".cub")} overwrite
set logging off
echo on
delete volume all except {skn}
delete block all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//"_skn.cub")} overwrite
```

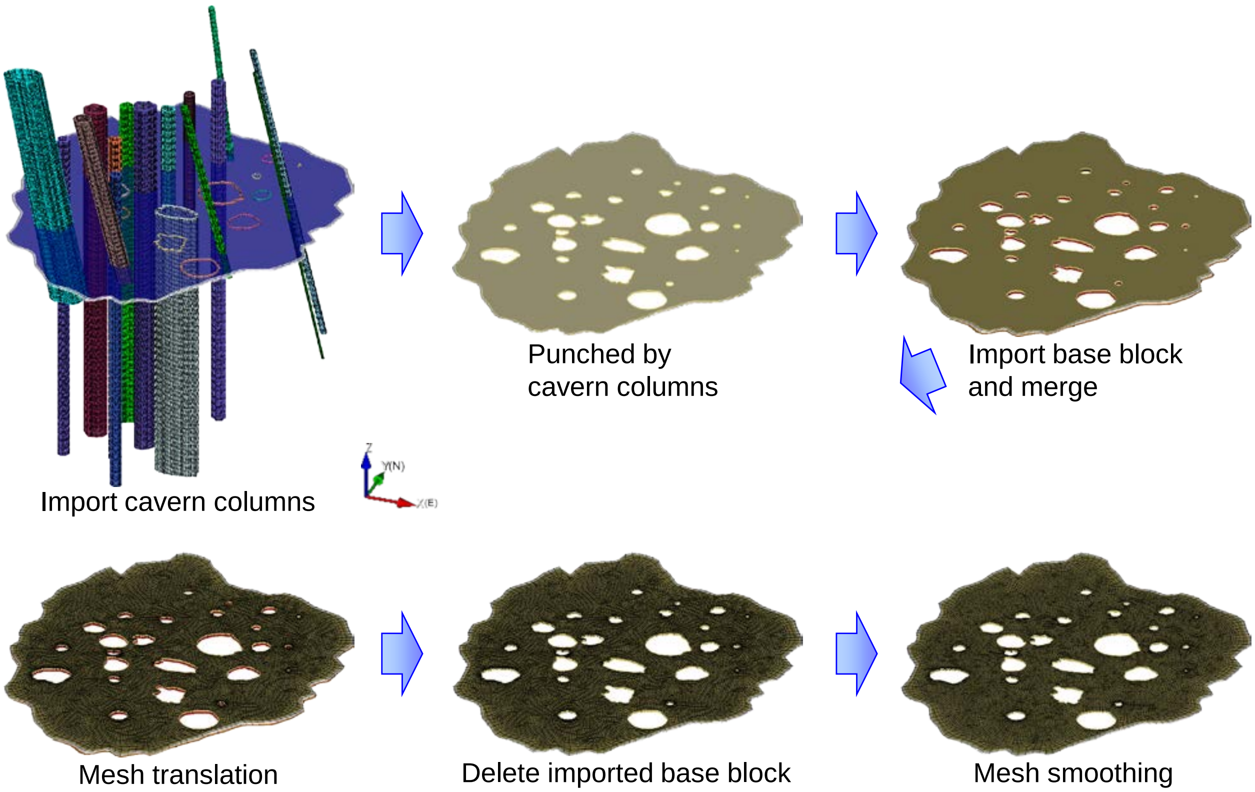


Figure 75: Steps to mesh the dome slice block right above the base dome slice block

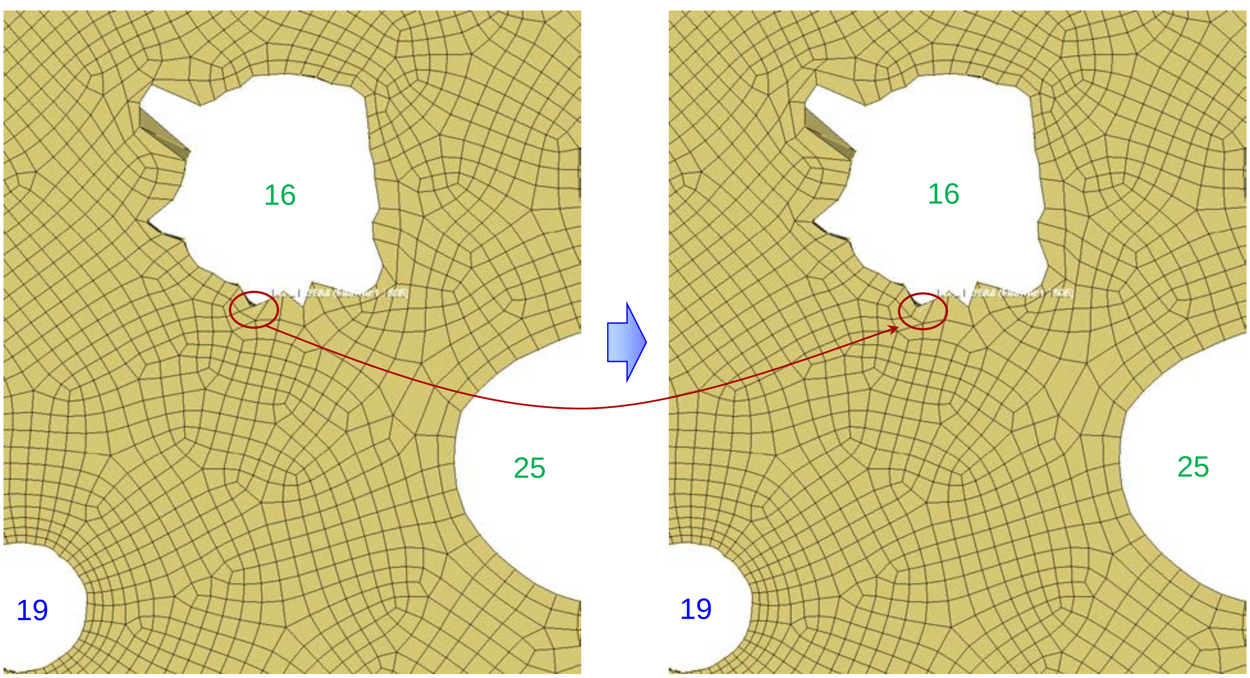


Figure 76: Smoothing improves the negative element into a positive element

6.5.5. Mesh downward

The mesh on the bottom of the base slice block is translated downward through every dome slice block under the base slice block. **`cubit_batch_run_down.txt`** (File 95) shows the Cubit play scripts to create meshed blocks which bottom elevations decrease from -2780 ft to -6300 ft with 20 ft thickness. Continuously, it creates the dome bottom block (-6400 ft bottom elevation).

Figure 77 shows the steps to create the meshed dome slice block right below the base dome slice block through the play file **`bot_2780.jou`** (File 96). **`vtx_2780.jou`** (File 97) defines parameters (**`define_parameters.jou`**, File 83) and imports the cavern columns (**`import_2720.jou`**, File 84). The dome slice block, which bottom elevation is -2780 ft, is punched by the cavern columns through **`create_vol.jou`** (File 92).

The dome slice block is meshed through **`mesh_wall.jou`** (File 98). The base dome slice block is imported to be used as the reference mesh block, and two blocks are merged together through the following scripts:

```
# Mesh ==============================================================
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-
TELE)//".cub")}
merge tol 0.05
merge all
```

The mesh on the bottom of the base dome slice block translates to the top of the dome slice block (-2780 ft), and then the block is meshed through the following scripts:

```
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
mesh volume {VLSC} {VDL1}
```

The imported base dome slice block is deleted. The inner dome slice block is defined as `Element Block 9992780`, the outer dome slice block (interface between dome and surrounding rock) is defined as `Element Block 9992781` through the following scripts:

```
# Delete unnecessaries ==============================================
delete block {TID} to {TID+NDL}
delete volume {VLSC+VDL1} {VLSC*2}
# Define Blocks =====================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
```

The poor quality shape elements on the bottom of the dome slice block are improved through the following scripts:

```
#### Smoothing ------------------------
###Initial minimum scaled jacobian = -0.776479 (Command Prompt, 60 repeats smooth
surface)
surface in sdl0b smooth scheme condition number cpu 5 # decrease cpu tim 10 to 5 min
smooth surface in sdl0b            # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.596e-02 (90249335)
```

As the final step, the meshed block is saved as Cubit file and Genesis file through **`save.jou`** (File 99).

These steps are repeated from -2800 ft to -6300 ft, then 177 meshed dome slice blocks are created below the base dome slice block.

File 95: cubit_batch_run_down.txt

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho -nojournal bot_2780.jou
Cubit –batch –nographics –noecho -nojournal bot_2800.jou
Cubit –batch –nographics –noecho -nojournal bot_2820.jou
Cubit –batch –nographics –noecho -nojournal bot_2840.jou
Cubit –batch –nographics –noecho -nojournal bot_2860.jou
.
.
.
Cubit –batch –nographics –noecho -nojournal bot_6220.jou
Cubit –batch –nographics –noecho -nojournal bot_6240.jou
Cubit –batch –nographics –noecho -nojournal bot_6260.jou
Cubit –batch –nographics –noecho -nojournal bot_6280.jou
Cubit –batch –nographics –noecho -nojournal bot_6300.jou
Cubit –batch –nographics –noecho -nojournal bot_6400_below.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\dome\vtx\
```

File 96: bot_2780.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_2780.jou")}
# Create Curve =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall.jou")}
# Save ===============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save.jou")}
#
exit
```

File 97: vtx_2740.jou

```
# Top elevation               : {TELE=       -2760   }ft
# Bottom elevation     : {BELE=       -2780   }ft
# Define parameters ==================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
# Import cub =========================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\import_2720.jou")}
```

File 98: mesh_wall.jou

```
# Mesh ==============================================================
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
### View bottom
graphics mode SmoothShade
view reset
rot 180 about y
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC} {VDL1} interval 1
mesh volume {VLSC} {VDL1}
# Delete unnecessaries =============================================
delete block {TID} to {TID+NDL}
delete volume {VLSC+VDL1} {VLSC*2}
# Define Blocks ====================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
#### Smoothing -----------------------
###Initial minimum scaled jacobian = -0.776479 (Command Prompt, 60 repeats smooth surface)
surface in sdl0b smooth scheme condition number cpu 5 # decrease cpu tim 10 to 5 min
smooth surface in sdl0b            # Minimum   (id) 1.667e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.344e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.515e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.543e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.572e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.588e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.594e-02 (90249335)
smooth surface in sdl0b            # Minimum   (id) 2.596e-02 (90249335)
```

File 99: save.jou

```
# Save ==============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_"//tostring(-BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\g0\dome_"//tostring(-BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_abstract.txt")} resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//".cub")} overwrite
set logging off
echo on
delete volume all except {skn}
delete block all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//"_skn.cub")} overwrite
```

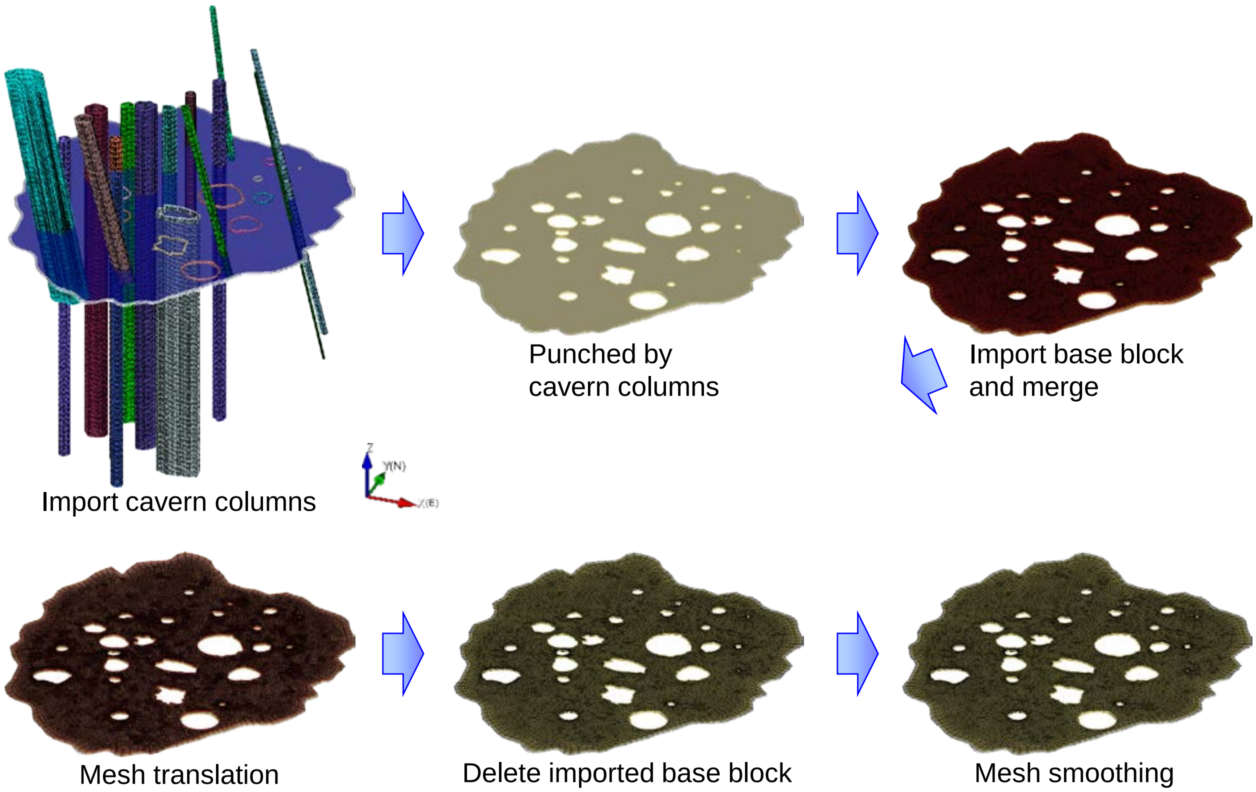


Figure 77: Steps to mesh the dome slice block right below the base dome slice block

To create the dome bottom block, **`bot_6400_below.jou`** (File 100) is used. **`vtx_6400.jou`** (File 101) defines parameters (**`define_parameters.jou`**, File 83) and imports the cavern columns (**`import_6300f.jou`**, File 102). The dome bottom block, which bottom elevation is -6400 ft, is punched by the cavern columns through **`create_vol.jou`** (File 92).

To mesh the block, the command line of **`mesh_below_wo_ss.jou`** (File 103) in File 100 is used. Figure 78 shows the steps to create the mesh into the dome bottom block. As the first step, the cavern columns are imported into the dome bottom block. As the second step, the dome bottom block is punched by the cavern columns. As the third step, the dome slice block, which bottom is 6300 ft, is imported right above the dome bottom block, and the bottom surfaces of the slice block and the top surfaces of the bottom block are merged to transfer the mesh. As the next step, the vertical curves of the volumes in the dome bottom block 100 ft height are divided by 20 ft, and then 5 intervals are created, and then the volumes in the dome bottom block are meshed entirely. As the last step, the imported volumes are deleted, and then meshed inner and skin volumes are defined as `Element Blocks 9996400` and `9996401`, respectively. The node set on the bottom of the dome bottom block is defined as `Nodeset 9990003` which will be added on the bottom node set of the entire model.

The meshed dome bottom block is saved through the command scripts in **`save_wo_ss.jou`** (File 104).

File 100: bot_6400_below.jou

```
# Setup environment  ==================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6400.jou")}
# Create Curve ========================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ================================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_below_wo_ss.jou")}
# Save ================================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_wo_ss.jou")}
#
exit
```

File 101: vtx_6400.jou

```
# Top elevation               : {TELE=       -6300   }ft
# Bottom elevation    : {BELE=       -6400   }ft
# Define parameters ===================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
# Import cub ==========================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\import_6300f.jou")}
```

File 102: import_6300f.jou

```
# Import cub ==========================================================
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc_dome\cub\bc_dome_"//tostring(-BELE)//".cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc001\cub\bc001_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc002\cub\bc002_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc003\cub\bc003_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc004\cub\bc004_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc006\cub\bc006_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc007\cub\bc007_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc008\cub\bc008_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc010\cub\bc010_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc011\cub\bc011_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc013\cub\bc013_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc015\cub\bc015_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc016\cub\bc016_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc017\cub\bc017_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc018\cub\bc018_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc019\cub\bc019_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc020\cub\bc020_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc024\cub\bc024_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc025\cub\bc025_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc026\cub\bc026_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc027\cub\bc027_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc028\cub\bc028_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc031_J1\cub\bc031_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc032_N1\cub\bc032_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc033_UTP\cub\bc033_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc101\cub\bc101_"//tostring(6400)//"_skn.cub")}
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\bc102\cub\bc102_"//tostring(6400)//"_skn.cub")}
```

File 103: mesh_below_wo_ss.jou

```
# Mesh ==============================================================
## Import horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-TELE)//".cub")}
merge tol 0.05
merge all
### View bottom
graphics mode SmoothShade
view reset
rot 180 about y
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
### Drawdown 1 ----------------------------------
curve in cdl1w interval {(TELE-BELE)/TL}
curve in cdl1w scheme equal
mesh curve in cdl1w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Dome itself -----------------
volume {VLSC} scheme Sweep  source surface in sdl0t target surface in sdl0b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VLSC}
### Interface between Dome and Surrounding rock ---
volume {VDL1} scheme Sweep  source surface in sdl1t target surface in sdl1b sweep_smooth Auto
sweep_transform least_squares  autosmooth_target off
mesh volume {VDL1}
# Delete unnecessaries =============================================
delete block {TID} to {TID+NDL}
delete volume {VLSC+VDL1} {VLSC*2}
# Define Blocks ====================================================
block {BID+VI0} volume {VLSC}
block {BID+VI1} volume {VDL1}
# Define Node Set ====================================================
nodeset {CID+3} surface in bsurf
```

File 104: save_wo_ss.jou

```
# Save ==============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_"//tostring(-BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\g0\dome_"//tostring(-BELE)//".g0")} overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\abs\dome_abstract.txt")} resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//".cub")} overwrite
set logging off
echo on
delete volume all except {skn}
delete block all
delete nodeset all
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//"_skn.cub")} overwrite
```

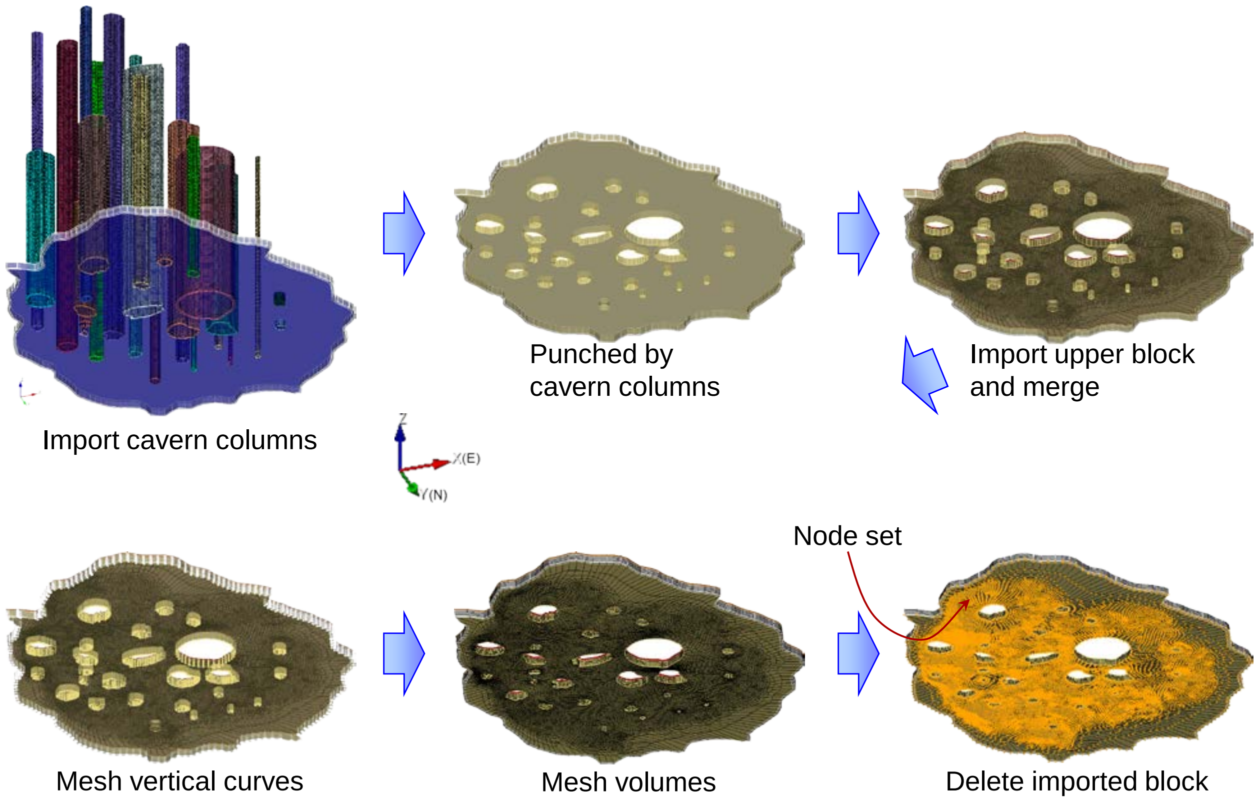


Figure 78: Steps to mesh the dome bottom slice block

6.5.6. Dome column

286 dome slice blocks created in Sections 6.5.3 through 6.5.5 are assembled into the BC-dome column as shown Figure 79 through the GJOIN process on RedSky. **`dome_wo_cavern.gjn`** (File 105) shows the GJOIN scripts. The Genesis file of dome column is saved as **`dome_wo_caverns.g1`** into the directory of `/fscratch/bypark/BC_sonar/mesh/domeg1/`. **`dome_wo_caverns.g1`** will be assembled into the entire model mesh named **`bc_20ft.g0`**.

The ID digits hereafter were described in Section 3.5. As the first step, two Genesis files **`dome_500.g0`** and **`dome_640.g0`** are combined with the tolerance of 1.E-02. The inner dome slice volume in the overburden layer (`Element Block 9990500, GJOIN ID 1`) is assigned to the overburden block in the entire model as `Element Block 2`. The outer dome skin slice volume in the overburden layer (`Element Block 9990501`) is combined to `Element Block 2`. The inner dome slice volume in the caprock layer (`Element Block 9990640, GJOIN ID 3`) is assigned to the caprock block in the entire model as `Element Block 3`. The outer dome skin slice volume in the caprock layer (`Element Block 9990641, GJOIN ID 4`) is assigned to the interface block between the dome and surrounding rock in the entire model as `Element Block 9`.

As the second step, the Genesis file **`dome_660.g0`** is combined to the combined two Genesis files above. The inner dome slice volume in the caprock layer (`Element Block 9990660`) is assigned to the caprock block in the entire model as `Element Block 3`. The outer dome skin slice volume in the caprock layer (`Element Block 9990661`) is combined to `Element Block 9`.

As the third step, the Genesis file **`dome_680.g0`** is combined to the combined three Genesis files above. The inner dome slice volume in the interbed layer (`Element Block 9990680, GJOIN ID 4`) is assigned to the interbed block in the entire model as `Element Block 8`. The outer dome skin slice volume in the interbed layer (`Element Block 9990681`) is combined to `Element Block 9`.

As the fourth step, the Genesis file **`dome_0700.g0`** is combined to the combined four Genesis files above. The inner dome slice volume in the salt dome layer (`Element Block 9990700, GJOIN ID is 5`) is assigned to the salt block in the entire model as `Element Block 1`. The outer dome skin slice volume in the salt dome layer (`Element Block 9990701`) is combined to `Element Block 9`.

As the fifth step, the Genesis file **`dome_0720.g0`** is combined to the combined five Genesis files above. The inner dome slice volume in the dome layer (`Element Block 9990720`) is assigned to the salt block in the entire model as `Element Block 1`. The outer dome skin slice volume in the dome layer (`Element Block 9990721`) is combined to `Element Block 9`.

In the same manner as the fifth step, the geneses files from **`dome_0740.g0`** through **`dome_6300.g0`** are combined.

As the last step, the Genesis file **`dome_6400.g0`** is combined to the combined 285 Genesis files above. The inner dome slice volume in the bottom salt block (`Element Block 9996400`) is assigned to the salt block in the entire model as `Element Block 1`. The outer dome skin slice volume in the bottom salt block (`Element Block 9996401`) is combined to `Element Block 9`.

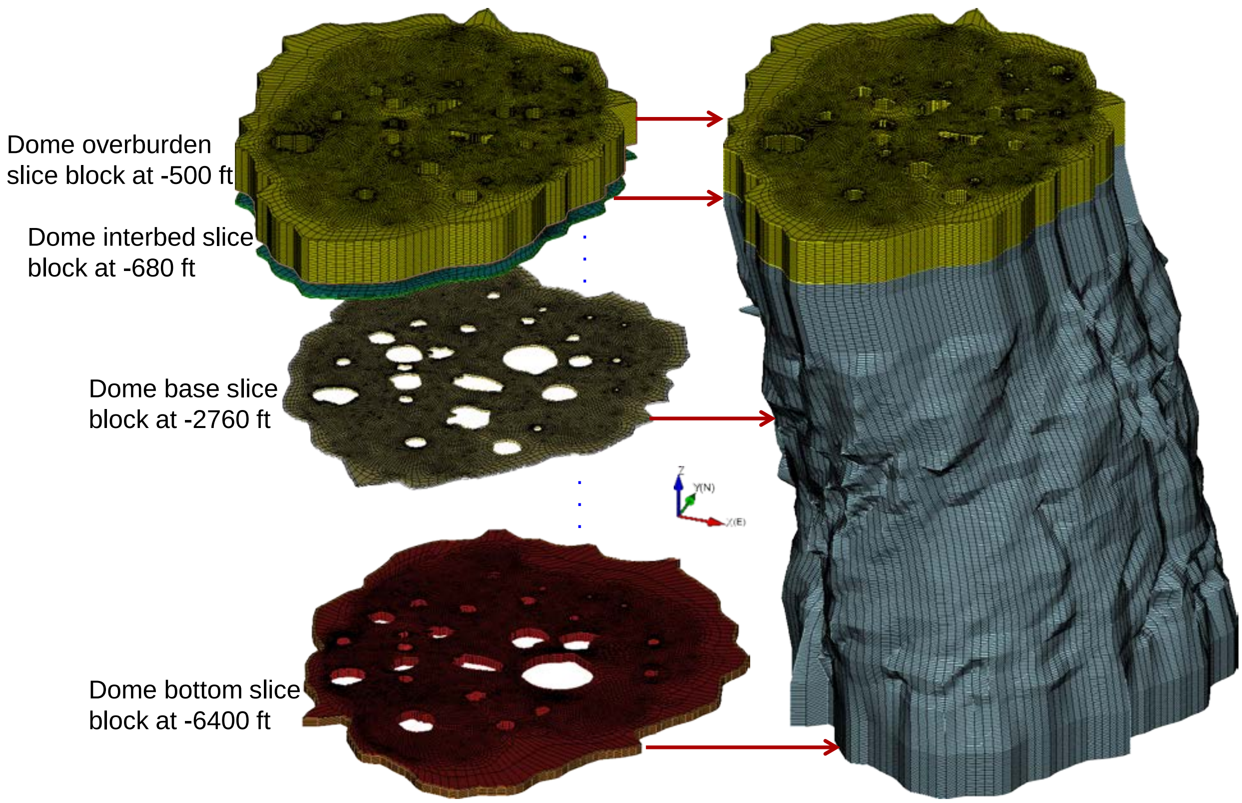


Figure 79: Dome column

File 105: dome_wo_caverns.gjn

```
/fscratch/bypark/BC_sonar/mesh/dome/dome_500.g0
/fscratch/bypark/BC_sonar/mesh/dome/dome_640.g0
comb
1.00E-02
no
blocks
id 1 2
combine 2 9990501
id 3 3
id 4 9
up

add
/fscratch/bypark/BC_sonar/mesh/dome/dome_660.g0
comb
1.00E-02
no
blocks
combine 3 9990660
combine 9 9990661
up

add
/fscratch/bypark/BC_sonar/mesh/dome/dome_680.g0
comb
1.00E-02
no
blocks
id 4 8
combine 9 9990681
up

add
/fscratch/bypark/BC_sonar/mesh/dome/dome_700.g0
comb
1.00E-02
no
blocks
id 5 1
combine 9 9990701
up

add
/fscratch/bypark/BC_sonar/mesh/dome/dome_720.g0
comb
1.00E-02
no
blocks
combine 1 9990720
combine 9 9990721
up
.
.
.
add
/fscratch/bypark/BC_sonar/mesh/dome/dome_6400.g0
comb
1.00E-02
no
blocks
combine 1 9996400
combine 9 9996401
up

finish
/fscratch/bypark/BC_sonar/mesh/domeg1/dome_wo_caverns.g1
```

6.6. Surrounding Rock

6.6.1. Cubit batch file

File 106 shows the Cubit batch run scripts to create the far-field surrounding the dome (called "Surrounding Rock"). These command scripts are executing on the Command Prompt Window as shown Figure 17. As the first step, the Cubit sub-journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_sub\`. As the next step, the vertex journal files are moved to the temporary directory of `C:\Sandia.dat\SPR\temp_vtx\`. As the third step, the prompt moves to the working directory of `C:\Sandia.dat\SPR\play_jou` and then Cubit batch commands are executed. After a series of Cubit batch journal files (File 106) execute completely, meshed 286 blocks are created.

File 106: Cubit batch run scripts for surrounding rock

```
move C:\Sandia.dat\SPR\BC_sonar\mesh\surround\sub\*.* C:\Sandia.dat\SPR\temp_sub\
move C:\Sandia.dat\SPR\BC_sonar\mesh\surround\vtx\*.* C:\Sandia.dat\SPR\temp_vtx\
cd C:\Sandia.dat\SPR\play_jou
Cubit –batch –nographics –noecho -nojournal bot_6400_base.jou
Cubit –batch –nographics –noecho -nojournal bot_6300_up.jou
Cubit –batch –nographics –noecho -nojournal bot_6280_up.jou
Cubit –batch –nographics –noecho -nojournal bot_6260_up.jou
Cubit –batch –nographics –noecho -nojournal bot_6240_up.jou
Cubit –batch –nographics –noecho -nojournal bot_6220_up.jou
.
.
.
Cubit –batch –nographics –noecho -nojournal bot_0720_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0700_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0680_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0660_up.jou
Cubit –batch –nographics –noecho -nojournal bot_0640_up_cr.jou
Cubit –batch –nographics –noecho -nojournal bot_0500_up_ob.jou
move C:\Sandia.dat\SPR\temp_sub\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\surround\sub\
move C:\Sandia.dat\SPR\temp_vtx\*.* C:\Sandia.dat\SPR\BC_sonar\mesh\surround\vtx\
```

6.6.2. Base surrounding rock slice block

The salt dome is modeled as being subjected to a regional far-field stresses acting from an infinite distance away. To apply the far-field boundary condition, the far-field blocks surrounding the dome are needed. The dome horizontal cross-section area at the bottom of the model (Ele. -6400 ft) is larger than at other elevations. The surrounding rock horizontal cross-section area is smaller than others, i.e. the surrounding rock area is getting larger with decreasing depth. Therefore, the bottom block of the surrounding rock is selected as the base block to optimize mesh shape quality.

`bot_6400_base.jou` (File 107) is the Cubit play scripts to create the surrounding rock block which bottom elevation is -6400 ft. **`vtx_6400`** (File 108) is the Cubit play scripts to set up the centers coordinates of the top and bottom of the block and execute **`define_parameters.jou`** (File 109).

As mentioned in Section 6.5.3, the dome area changes with depth. Therefore, the center coordinates of the dome area changes with depth. The centers of the top and bottom of the surrounding rock slice block at each elevation are made matching to the centers of dome slice block for the mesh quality. The center coordinates of the dome area at -6300 ft is calculated to be (74.46, 193.22). The center coordinates of the dome area at -6400 ft is assumed to be the same as at -6300 ft.

The dome widths in the E-W and N-S directions at -6300 ft are calculated to be 4525.84 ft and 5259.12 ft, respectively. The widths of the surrounding rock in the E-W and N-S directions are about two times the widths of dome, respectively. The lengths of the surrounding rock in the E-W and N-S directions at -6300 ft are calculated to be 9100 ft and 11000 ft, respectively.

File 107: bot_6400_base.jou

```
# Setup environment  =================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =======================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6400.jou")}
# Create Curve ========================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ================================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_base.jou")}
# Save ================================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_base.jou")}
#
exit
```

File 108: vtx_6400

```
# Top elevation               : {TELE=       -6300   }ft
# Bottom elevation    : {BELE=       -6400   }ft
# X-Coordinate at the center of dome section at TELE: {XCODT=74.46}
# Y-Coordinate at the center of dome section at TELE: {YCODT=193.22}
# X-Coordinate at the center of dome section at BELE: {XCODB=74.46}
# Y-Coordinate at the center of dome section at BELE: {YCODB=193.22}
# Define parameters =================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
```

File 109: define_parameters.jou

```
# Define Parameters =================================================
# Height of layer      : {h_lyr= TELE-BELE} ft
# E-W width of Model   : {EW_MD=      9100    }ft # Maximum E-W width of dome at 6300 ft = 4525.84 ft
# N_S width of Model   : {NS_MD=      11000   }ft # Maximum N-W width of dome at 6300 ft = 5259.12 ft
# Number of intervals on E-W curves: {NIEW=20}
# Number of intervals on N-S curves: {NINS=20}
# X-Declination from bottom: {XDFS=XCODT-XCODB}
# Y-declination from bottom: {YDFS=YCODT-YCODB}
# X-Coordinate at the center of entire dome: {XCOED=0}
# Y-Coordinate at the center of entire dome: {YCOED=0}
# Moved X-Coordinate at center of the dome section: {MXCOD=XCODB-XCOED}
# Moved Y-Coordinate at center of the dome section: {MYCOD=YCODB-YCOED}
# Bottom surface ID: {BSID=1}
# Top surface ID: {TSID=2}
# Volume ID: {V_SR=1}
Graphics Mode Transparent
view reset
rot  20 about z
rot -60 about x
#
Logging   Errors   on   file   {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\err\surr_"//tostring(-
BELE)//".err")}
Set    logging    on    file    {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\log\surr_"//tostring(-
BELE)//".log")}
```

Figure 80 shows the steps to create the meshed base surrounding rock slice block which bottom elevation is -6400 ft.

Step 1: Create the bottom rectangular surface which widths in E-W and N-S directions are 9100 ft and 11000 ft, respectively, and then create the volume considering the declination of the vertical edges (File 110).

Step 2: Import the interface slice volume which bottom elevation is -6400 ft (File 110).

Step 3: Punch the surround rock slice block with the imported interface slice volume (File 110). Define the groups as naming in Table 4 (File 111).

Step 4: Four edges of the top surface are divide by 20, then 20 nodes are created on each edge (File 112).

Step 5: Mesh the top surface. One mesh line at least is created at each node on the perimeter of the dome and surrounding rock edges (File 112).

Step 6: Mesh the vertical curves. The vertical curves of the volume 100 ft thick are divided by 20 ft, then five intervals are created (File 112).

Step 7: The mesh on the top surfaces of the volume are translated to the bottom surface with five element levels (File 112).

Step 8: Define the volume as `Element Block 56400`, the east and west sides as `Nodeset 16400`, the north and south side as `Nodeset 26400`, and the bottom surface as `Nodeset 3` (File 112).

Step 9: Save the Cubit and Genesis files (File 113).

File 110: create_vol.jou

```
# Create volume (Surrounding rock) ============================
## bottom rectangular surface ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
create surface rectangle width {EW_MD} height {NS_MD} zplane
## volume ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
sweep surface {BSID} direction {XDFS} {YDFS} {h_lyr} distance
move volume {V_SR} x {MXCOD} y {MYCOD} z {BELE}
# Import cub ======================================================
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\dome\cub\dome_"//tostring(-BELE)//"_skn.cub")}
# Webcut ==========================================================
webcut volume {V_SR} tool volume {V_SKN=7}
delete volume {V_SR} {V_SKN} {V_SKN+1}
# Surround Volume: {VLSC=V_SKN+2}
# Define group ====================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_group_surr.jou")}
# Remove unexpected vertices ======================================
vertex vis on
simplify curve all except curve      in tsurf bsurf
vertex vis off
zoom reset
```

File 111: define_group_surr.jou

```
## Define group ===================================================
group "tcurv" add curve in volume all with z_coord > {TELE-0.1}
group "bcurv" add curve in volume all with z_coord < {BELE+0.1}
group "tsurf" add surface in volume all with z_coord > {TELE-0.1}
group "bsurf" add surface in volume all with z_coord < {BELE+0.1}
group "msurf" add surface in volume all
group "msurf" remove surface in tsurf
group "msurf" remove surface in bsurf
### Drawdown 0 (Initial Dome) ------------------
#### Vertices on top of the volume
group "vdl0t" add vertex in volume {VLSC} with z_coord > {TELE-0.1}
#### Curves on outside wall of the volume
group "cdl0w" add curve in volume {VLSC}
group "cdl0w" remove curve in tcurv
group "cdl0w" remove curve in bcurv
#### Curves on E-W sides
group "cew" add curve in volume all with x_coord > {(EW_MD/2-10.0)+MXCOD}
group "cew" add curve in volume all with x_coord < {(-EW_MD/2+10.0)+MXCOD}
group "cew" remove curve in cdl0w
#### Curves on N-S sides
group "cns" add curve in volume all with y_coord > {(NS_MD/2-10.0)+MYCOD}
group "cns" add curve in volume all with y_coord < {(-NS_MD/2+10.0)+MYCOD}
group "cns" remove curve in cdl0w
#### Surfaces on bottom of the volume
group "sbot" add surface in volume {VLSC}
group "sbot" remove surface in msurf
group "sbot" remove surface in tsurf
#### Surfaces on E-W sides
group "sew" add surface in volume all with x_coord > {(EW_MD/2-10.0)+MXCOD}
group "sew" add surface in volume all with x_coord < {(-EW_MD/2+10.0)+MXCOD}
#### Surfaces on N-S sides
group "sns" add surface in volume all with y_coord > {(NS_MD/2-10.0)+MYCOD}
group "sns" add surface in volume all with y_coord < {(-NS_MD/2+10.0)+MYCOD}
```

File 112: mesh_base.jou

```
# Mesh ==============================================================
## Create horizontal reference mesh ~~~~~~~~~~~~~~~~~~~~~~~
curve in cew interval {NIEW}
curve in cns interval {NINS}
mesh curve in cew cns
### Surrounding rock itself ------------------
surface in tsurf vertex in vdl0t type side
surface in tsurf interval 1
mesh surface in tsurf
#### Smoothing until no smoothing needed --------
smooth surface in tsurf
surface in tsurf smooth scheme cond
smooth surface in tsurf
smooth surface in tsurf
smooth surface in tsurf
smooth surface in tsurf
## mesh vertical curves ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
### Thickness of one layer = {TL=20} ft
### Drawdown 0 (Initial Cavern) -----------------
curve in cdl0w interval {(TELE-BELE)/TL}
curve in cdl0w scheme equal
mesh curve in cdl0w
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC}interval 1
mesh volume {VLSC}
# Define Blocks ====================================================
block {50000-BELE} volume {VLSC}
# Define Node Set ====================================================
nodeset {10000-BELE} surface in sew
nodeset {20000-BELE} surface in sns
nodeset 3 surface in sbot
```

File 113: save_base.jou

```
# Save ===============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\abs\surr_"//tostring(-
BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export mesh {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\g0\surr_"//tostring(-BELE)//".g0")}
overwrite
echo off
set logging on file {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\abs\surr_abstract_up.txt")}
resume
quality volume all
compress node
compress element
save as {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\cub\surr_"//tostring(-BELE)//".cub")}
overwrite
set logging off
```

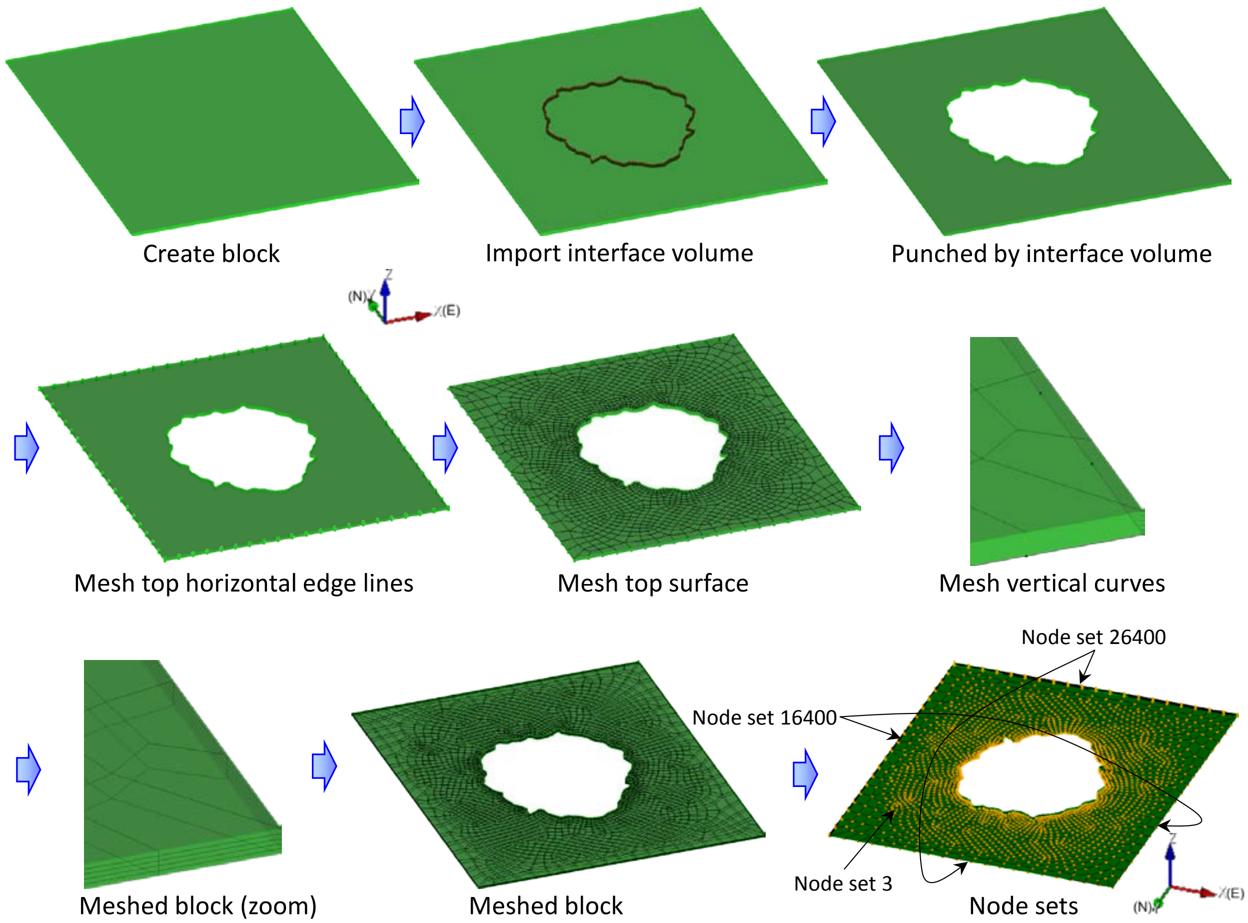


Figure 80: Steps to create and mesh the base surrounding rock slice block at elvati -6400 ft

6.6.3. Surrounding rock slice blocks

`bot_6300.jou` (File 114) is the Cubit play scripts to create the surrounding rock block which bottom elevation is -6300 ft. **`vtx_6300`** (File 115) is the Cubit play scripts to set up the centers coordinates of the top and bottom of the block and execute **`define_parameters.jou`** (File 109).

File 114: bot_6300_up.jou

```
# Setup environment  ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\setup.jou")}
# Create vertex =====================================================
play {Quote("C:\Sandia.dat\SPR\temp_vtx\vtx_6300.jou")}
# Create Curve ======================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\create_vol.jou")}
# Mesh ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\mesh_wall_up_bot.jou")}
# Save ==============================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\save_up.jou")}
#
exit
```

File 115: vtx_6300

```
# Top elevation               : {TELE=       -6280   }ft
# Bottom elevation     : {BELE=       -6300   }ft
# X-Coordinate at the center of dome section at TELE: {XCODT=74.46}
# Y-Coordinate at the center of dome section at TELE: {YCODT=193.22}
# X-Coordinate at the center of dome section at BELE: {XCODB=74.46}
# Y-Coordinate at the center of dome section at BELE: {YCODB=193.22}
# Define parameters ================================================
play {Quote("C:\Sandia.dat\SPR\temp_sub\define_parameters.jou")}
```

Figure 81 shows the steps to create and mesh the surrounding rock slice block which bottom elevation is -6300 ft.

Step 1: Create the bottom rectangular surface which widths in E-W and N-S directions are 9100 ft and 11000 ft, respectively, and then create the volume considering the declination of the vertical edges (File 110).

Step 2: Import the interface slice volume which bottom elevation is -6400 ft (File 110).

Step 3: Punch the surround rock slice block with the imported interface slice volume (File 110).

Step 4: Import the base block created in Section 6.6.2 (File 116).

Step 5: Mesh the block (File 116).

Step 6: Delete the imported base block (File 116).

Step 8: Define the block as `Element Block 56300`, the east and west sides as `Nodeset 16300`, the north and south sides as `Nodeset 26300` (File 116).

Step 9: Save the Cubit and Genesis files (File 117).

These steps repeat to create the meshed surrounding rock slice blocks from -6280 ft to the surface through the Cubit batch run scripts in File 106.

File 116: mesh_wall_up_bot.jou

```
# Mesh ===============================================================
### Import reference mesh -----------------------
import {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\cub\surr_"//tostring(-BELE+100)//".cub")}
merge tol 0.05
merge all
### View bottom
graphics mode SmoothShade
view reset
## Mesh volumes ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
volume {VLSC}interval 1
mesh volume {VLSC}
# Delete unnecessaries ==============================================
delete block {50000-BELE+100}
delete nodeset 3 {10000-BELE+100} {20000-BELE+100}
delete volume {VLSC*2}
# Define Blocks =====================================================
block {50000-BELE} volume {VLSC}
# Define Node Set ======================================================
nodeset {10000-BELE} surface in sew
nodeset {20000-BELE} surface in sns
```

File 117: save_up.jou

```
# Save ===============================================================
delete group all
view reset
rot -20 about z
rot -60 about x
set logging off
set    logging    on    file    {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\abs\surr_"//tostring(-
BELE)//".abs")}
quality volume all Shape high 1 low 0.1 global draw mesh
export    mesh    {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\g0\surr_"//tostring(-BELE)//".g0")}
overwrite
echo off
set   logging   on   file   {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\abs\surr_abstract_up.txt")}
resume
quality volume all
compress node
compress element
save     as     {Quote("C:\Sandia.dat\SPR\BC_sonar\mesh\surround\cub\surr_"//tostring(-BELE)//".cub")}
overwrite
set logging off
echo on
```

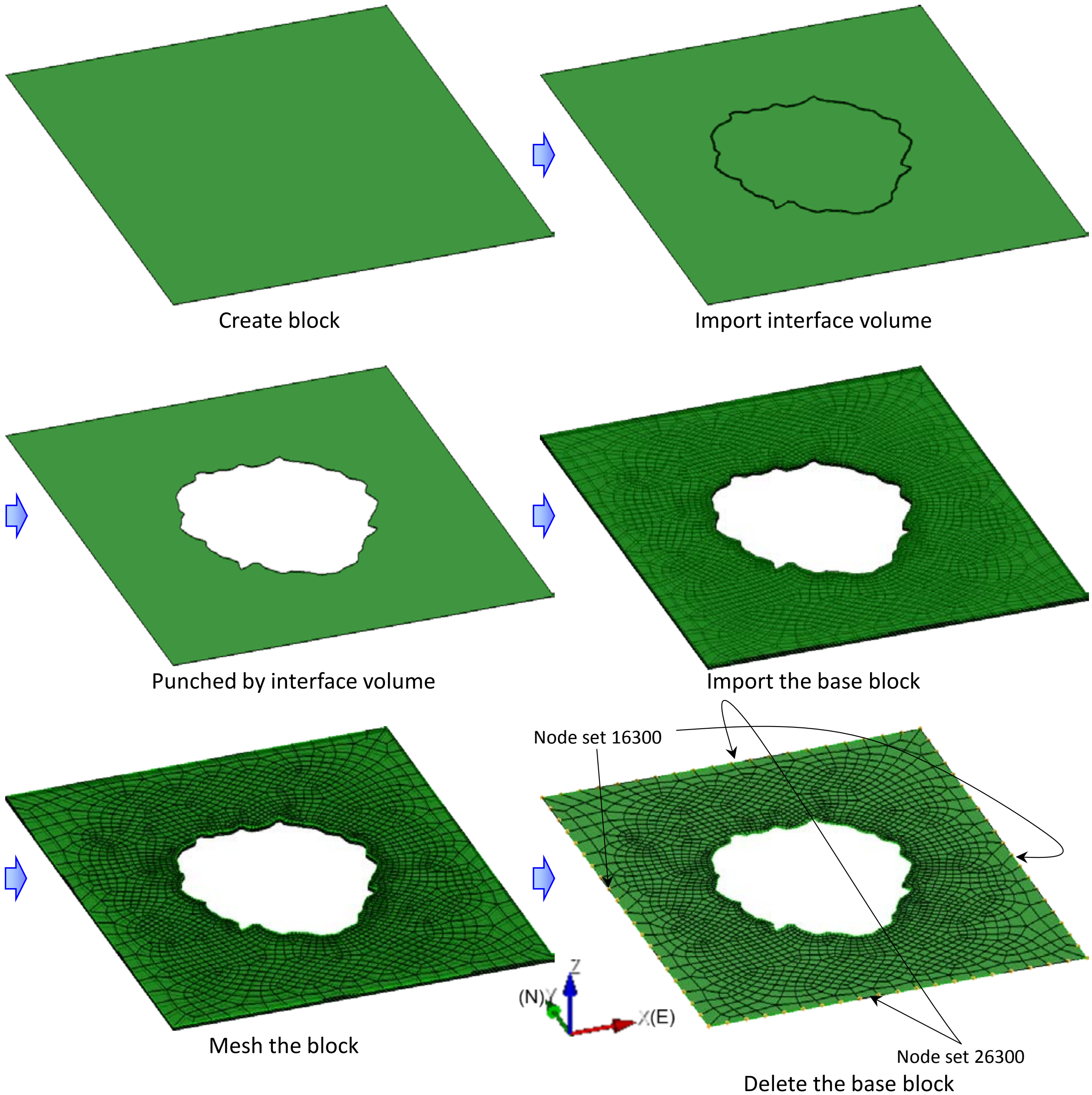


Figure 81: Steps to create and mesh the surrounding rock slice block at elevation -6300 ft

6.6.4. Surrounding rock column

286 surrounding rock slice blocks created in Sections 6.6.2 and 6.6.3 are assembled into the BC-surrounding rock column as shown Figure 82 through the GJOIN process on RedSky. **`surr.gjn`** (File 118) shows the GJOIN scripts. The Genesis file of dome column is saved as **`surr.g1`** into the directory of `/fscratch/bypark/BC_sonar/mesh/surrg1/`. **`surr.g1`** will be assembled into the entire model mesh named **`bc_20ft.g0`**.

The ID digits hereafter were described in Section 3.5. As the first step, two Genesis files **`surr_500.g0`** and **`surr_640.g0`** are combined with the tolerance of 1.E-02. `Nodeset 10500` of **`surr_500.g0`** and `Nodeset 10640` of **`surr_640.g0`** are combined with the tolerance of 1.E-02. The

Nodeset 20500 of **surr_500.g0** and Nodeset 20640 of **surr_640.g0** are combined with the tolerance of 1.E-02. The surrounding rock slice volume of **surr_500.g0** in the overburden layer (Element Block 50500, GJOIN ID 1) is assigned to the overburden block in the entire model as Element Block 2. The surrounding rock slice volume of **surr_640.g0** in the caprock layer (Element Block 50640, GJOIN ID 2) is assigned to the surrounding rock in the entire model as Element Block 5. The node set on the E-W sides of **surr_500.g0** (NSET 10500, GJOIN ID 1) is assigned to the E-W node set in the entire model as NSET 1. The node set on the N-S sides of **surr_500.g0** (NSET 20500, GJOIN ID 2) is assigned to the N-S node set in the entire model as NSET 2. The node set on the E-W sides of **surr_640.g0** (NSET 10640) is combined to the E-W node set in the entire model as NSET 1. The node set on the N-S sides of **surr_640.g0** (NSET 20640) is combined to the N-S node set in the entire model as NSET 2.

As the second step, the Genesis file **surr_660.g0** is combined to the combined two Genesis files above. The Nodesets 10660 and 20660 of **surr_660.g0** are combined to the node sets of the combined two Genesis files above with the tolerance of 1.E-02. The surrounding rock slice volume of **surr_660.g0** (Element Block 50660) is combined to the surrounding rock in the entire model as Element Block 5. The node set on the E-W sides of **surr_660.g0** (NSET 10660) is combined to the E-W node set in the entire model as NSET 1. The node set on the N-S sides of **surr_660.g0** (NSET 20660) is combined to the N-S node set in the entire model as NSET 2.

In the same manner as the second step, the geneses files from **dome_0680.g0** through **dome_6300.g0** are combined.

As the last step, the Genesis file **surr_6400.g0** is combined to the combined Genesis files above. The Nodesets 16400 and 26400 of **surr_6400.g0** are combined to the node sets of the combined Genesis files above with the tolerance of 1.E-02. The surrounding rock slice volume of **surr_6400.g0** (Element Block 56400) is combined to the surrounding rock in the entire model as Element Block 5. The node set on the E-W sides of **surr_6400.g0** (NSET 16400) is combined to the E-W node set in the entire model as NSET 1. The node set on the N-S sides of **surr_6400.g0** (NSET 20660) is combined to the N-S node set in the entire model as NSET 2. The node set on the bottom surface of **surr_6400.g0** (GJOIN ID 3) is assigned to the E-W node set in the entire model as NSET 3.

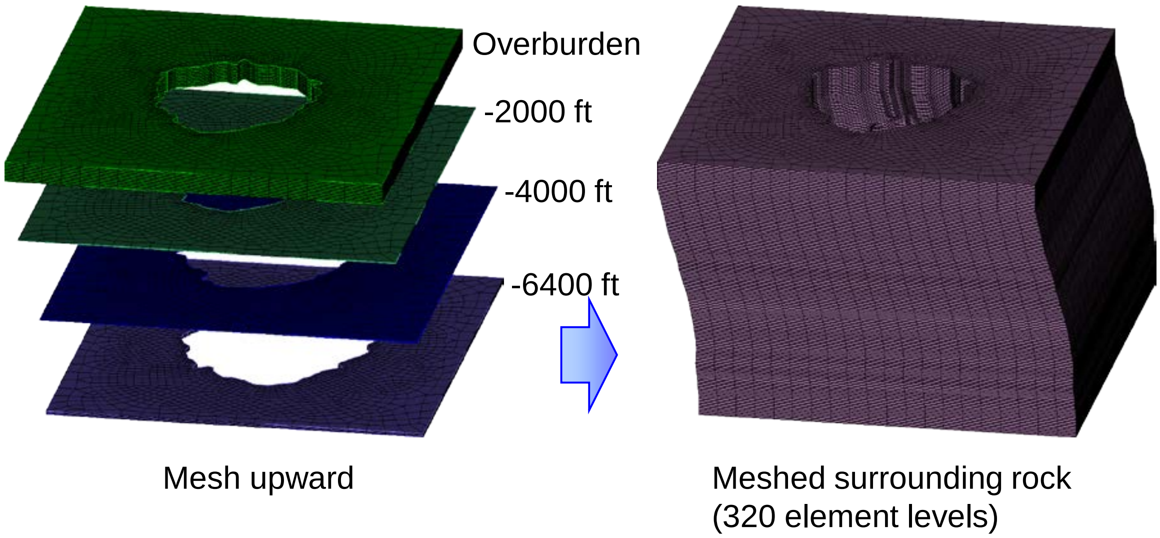


Figure 82: Surrounding rock column

File 118: surr.gjn

```
/fscratch/bypark/BC_sonar/mesh/surr/surr_500.g0
/fscratch/bypark/BC_sonar/mesh/surr/surr_640.g0
comb
yes
10500 10640
1.00E-02
comb
yes
20500 20640
1.00E-02
comb
no
1.00E-02
no
blocks
id 1 2
id 2 5
up
nset
id 1 1
id 2 2
combine 1 10640
combine 2 20640
up

add
/fscratch/bypark/BC_sonar/mesh/surr/surr_660.g0
comb
yes
1 10660
1.00E-02
comb
yes
2 20660
1.00E-02
comb
no
1.00E-02
no
blocks
combine 5 50660
up
nset
combine 1 10660
combine 2 20660
up

.
.
.
add
/fscratch/bypark/BC_sonar/mesh/surr/surr_6400.g0
comb
yes
1 16400
1.00E-02
comb
yes
2 26400
1.00E-02
comb
no
1.00E-02
no
blocks
combine 5 56400
up
nset
combine 1 16400
combine 2 26400
id 3 3
up

finish
/fscratch/bypark/BC_sonar/mesh/surrg1/surr.g1
```

7. ASSEMBLE

7.1. Dome and Cavern Columns

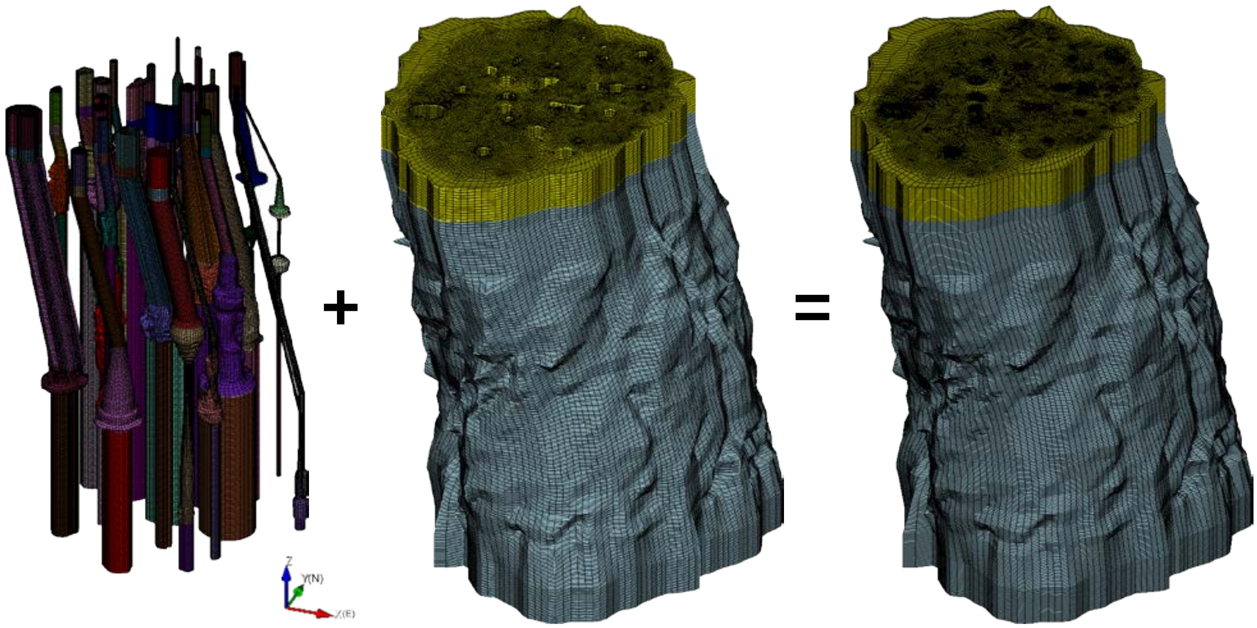
26 cavern columns and dome column created in Sections 6.1 through 6.5 are combined into the BC-dome as shown Figure 83 through the GJOIN process on RedSky. **`dome.gjn`** (File 119) shows the GJOIN scripts. The Genesis file of the dome is saved as **`dome.g1`** into the directory of `/fscratch/bypark/BC_sonar/mesh/domeg1/`. **`dome.g1`** will be assembled into the entire model mesh named **`bc_20ft.g0`**.

The ID digits hereafter were described in Section 3.5. As the first step, `Nodeset 3001` on the bottom of BC-1 cavern column is combined into `Nodeset 9990003` on the bottom of dome column with the tolerance of 1.E-02. Two Genesis files **`dome_wo_caverns.g1`** (Dome column) and **`bc001.g1`** (BC-1 cavern column) are combined with the tolerance of 1.E-02. The cavern slice block in the salt layer (`Element Block 1001, GJOIN ID 9`) is combined into the dome slice block in the salt layer (`Element Block 1, GJOIN ID 9`). The cavern slice block in the overburden layer (`Element Block 2001, GJOIN ID 6`) is combined into the dome slice block in the overburden layer (`Element Block 2, GJOIN ID 1`). The cavern slice block in the caprock layer (`Element Block 3001, GJOIN ID 7`) is combined into the dome slice block in the caprock layer (`Element Block 3, GJOIN ID 2`). The cavern slice block in the interbed layer (`Element Block 8001, GJOIN ID 8`) is combined into the dome slice block in the interbed layer (`Element Block 8, GJOIN ID 4`). The node set on the bottom of cavern column (`NSET 9990003, GJOIN ID 1`) is renamed `NSET 3`. The node set on the bottom of cavern column (`NSET 3001, GJOIN ID 2`) is combined into the node set on the bottom of dome column (`NSET 3, GJOIN ID 1`).

As the second step, `Nodeset 3002` on the bottom of BC-2 cavern column is combined into `Nodeset 3` on the bottom of dome column with the tolerance of 1.E-02. The Genesis file **`bc002.g1`** (BC-2 cavern column) is added to the combined Genesis file above with the tolerance of 1.E-02. The cavern slice block in the salt layer (`Element Block 1002, GJOIN ID 11`) is combined into the dome slice block in the salt layer (`Element Block 1, GJOIN ID 5`). The cavern slice block in the overburden layer (`Element Block 2002, GJOIN ID 8`) is combined into the dome slice block in the overburden layer (`Element Block 2, GJOIN ID 1`). The cavern slice block in the caprock layer (`Element Block 3002, GJOIN ID 9`) is combined into the dome slice block in the caprock layer (`Element Block 3, GJOIN ID 2`). The cavern slice block in the interbed layer (`Element Block 8002, GJOIN ID 10`) is combined into the dome slice block in the interbed layer (`Element Block 8, GJOIN ID 4`). The node set on the bottom of cavern column (`NSET 3002, GJOIN ID 2`) is combined into the node set on the bottom of dome column (`NSET 3, GJOIN ID 1`).

In the same manner as the second step, the geneses files of **`bc003.g1`** through **`bc102.g1`** are combined into the dome column block.

As the last step, the Genesis file of the dome column block containing 26 cavern columns is saved as **`dome.g1`**.



Cavern Columns Dome Column BC-Dome

Figure 83 Cavern columns and dome column are combined into BC-Dome

File 119: dome.gjn

```
/fscratch/bypark/BC_sonar/mesh/domeg1/dome_wo_caverns.g1
/fscratch/bypark/BC_sonar/mesh/bc001g1/bc001.g1
comb
yes
9990003 3001
1.00E-02
comb
no
1.00E-02
no
blocks
combine 1 1001
combine 2 2001
combine 3 3001
combine 8 8001
up
nset
id 1 3
combine 3 3001
up

add
/fscratch/bypark/BC_sonar/mesh/bc002g1/bc002.g1
comb
yes
3 3002
1.00E-02
comb
no
1.00E-02
no
blocks
combine 1 1002
combine 2 2002
combine 3 3002
combine 8 8002
up
nset
combine 3 3002
up

.
.
.
add
/fscratch/bypark/BC_sonar/mesh/bc102g1/bc102.g1
comb
yes
3 3102
1.00E-02
comb
no
1.00E-02
no
blocks
combine 1 1102
combine 2 2102
combine 3 3102
combine 8 8102
up
nset
combine 3 3102
up

finish
/fscratch/bypark/BC_sonar/mesh/domeg1/dome.g1
```

7.2. Entire Model

The dome column assembled in Section 7.1 and surrounding rock column created in Section 6.6 are combined into the entire BC-model as shown Figure 84 through the GJOIN process on

RedSky. **`assemble_all.gjn`** (File 119) shows the GJOIN scripts. `Nodeset 3` on the bottom of the surrounding rock column (`NSET 3, GJOIN ID 4`) is combined into `Nodeset 3` on the bottom of dome column with the tolerance of 1.E-02. Two Genesis files **`dome.g1`** (dome column) and **`surr.g1`** (surrounding rock column) are combined with the tolerance of 1.E-02. The Genesis file of the entire BC-model is saved as **`bc_20ft.g2`** into the directory of `/fscratch/bypark/BC_sonar/mesh/all_g2/`.

The geologic temperature data will be added on **`bc_20ft.g2`**, and then saved as **`bc_20ft.g0`**. Finally, the entire model mesh named **`bc_20ft.g0`** is constructed. Figure 85 shows the overview of the hexahedral finite element mesh of the stratigraphy and cavern field at Bayou Choctaw. The mesh consists of 7,544,463 nodes and 7,507,840 elements with 170 element blocks, 3 node sets, and 55 side sets.

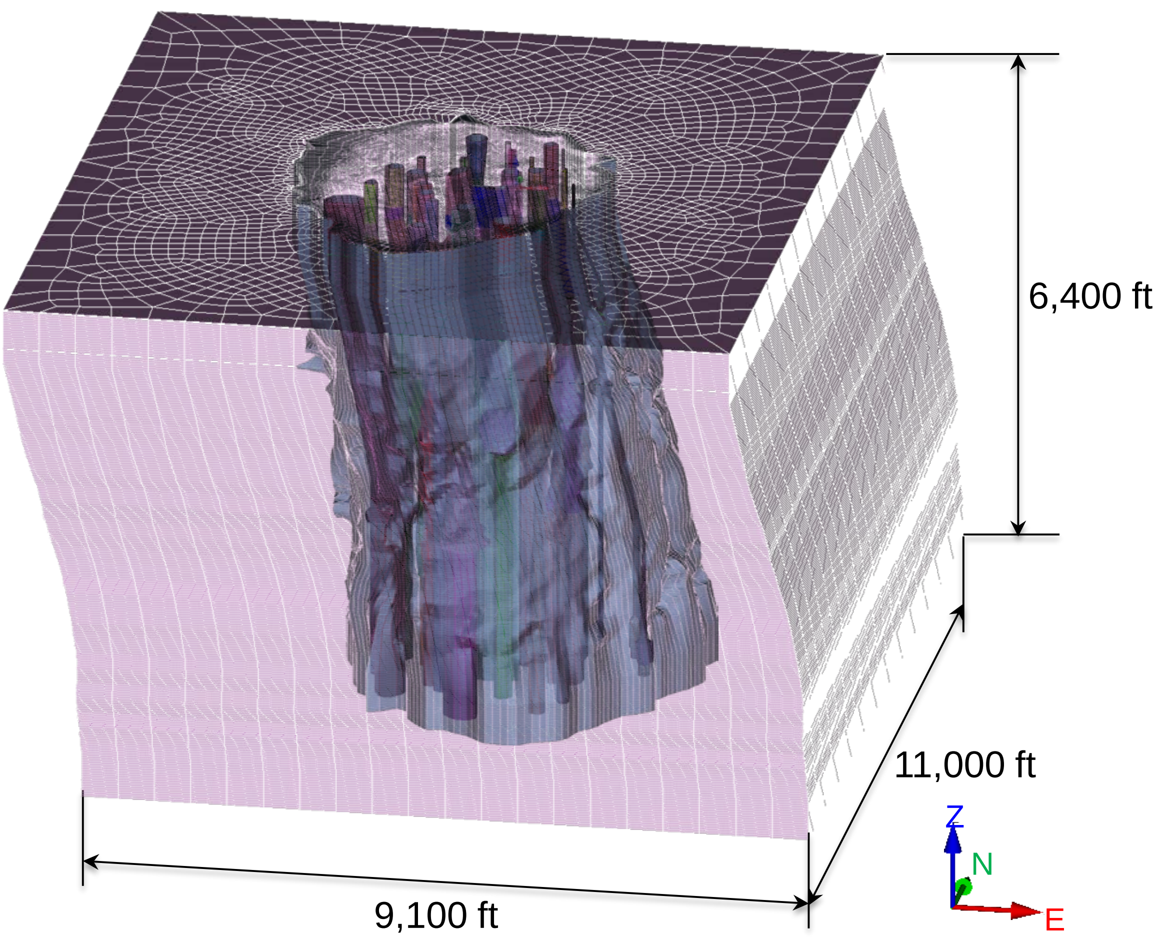


Figure 84: Entire BC-model

File 120: assemble_all.gjn

```
/fscratch/bypark/BC_sonar/mesh/domeg1/dome.g1
/fscratch/bypark/BC_sonar/mesh/surrg1/surr.g1
comb
yes
3 3
1.00E-02
comb
no
1.00E-02
no

finish
/fscratch/bypark/BC_sonar/mesh/all_g2/bc_20ft.g2
```

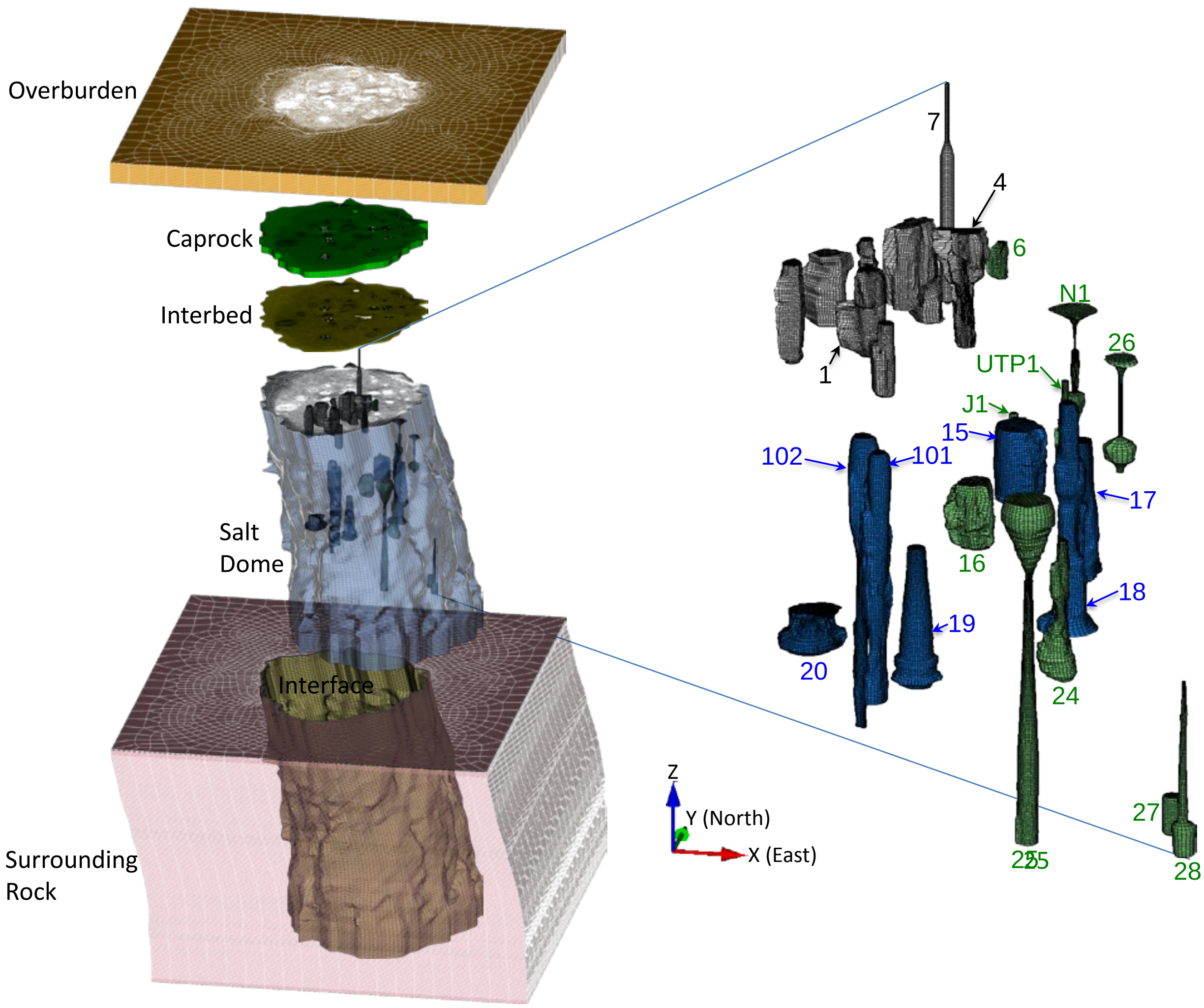


Figure 85: Overview of the hexahedral finite element mesh of the stratigraphy and cavern field at Bayou Choctaw

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8. CONCLUSIONS

The three-dimensional FE mesh capturing realistic geometries of Bayou Choctaw site has been constructed using the sonar and seismic survey data obtained from the field. Various ideas and techniques to construct the mesh capturing artificially and naturally formed geometries are introduced. The steps and methodologies in this report could be applied to construct the meshes of Big Hill, Bryan Mound, and West Hackberry SPR sites. The constructed mesh documented in this report is currently being used in large-scale numerical simulations of the geomechanical behavior of the Bayou Choctaw oil storage facility. The results of those simulation will be documented in a future SAND report.

The ideas and techniques could be applied to various cases. For example, the caverns and salt dome in this report are tall (vertically long), so the volumes are divided by horizontal slice blocks 20 ft thick. A tunnel or horizontally long structure in mountains or subsurface can be divided by vertical slice blocks with any thickness. The methodology could be applied to the complicated shape masses for not only various civil and geological structures but also biological applications such as artificial limbs.

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9. REFERENCES

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