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Byoung Yoon Park
Principal Member of Technical Staff
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07/30/2021

US DOE SPR PMO, New Orleans, LA

Dear: Diane Willard, DOE-SPR

Subject: Milestone ***1.2b1: Interpolation data transfer between the models before and after a partial drawdown leach in BH***

It has been recognized that as cavern operations become more frequent due to oil sales, field conditions may arise which require a faster turnaround time of analysis to address potential cavern impacts. This letter describes attempts to implement a strategy of transferring an intermediate solution of a Big Hill (BH) geomechanical model from a previous finite element mesh with a specified cavern geometry, to a new mesh with a new cavern geometry created by leaching from an oil sale operation.

In FY20, the interpolation data transfer between the models before and after the partial drawdown leach due to oil sell has been studied. The existing model considered full drawdown leach every five years for the future oil drawdown activities. Modeling of the leaching process of the caverns has been 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. In actual, partial drawdown leaches were/will be conducted rather than full drawdown due to oil sell in four Strategic Petroleum Reserve (SPR) sites. To consider the partial drawdown, the interpolation data transfer technique should be applied rather than deleting the pre-meshed block. The technique studied in FY20 will be enhanced and applied to an actual situation that happened at BH.

The steps in the SPR geomechanical simulation are, (1) Create a mesh capturing the realistic geometries of caverns, salt dome, and caprock using the data obtained from sonar, seismic, and borehole surveys, (2) Calculate cavern volume changes and surface subsidence due to salt creep by applying the internal pressure change to the inner surface of the cavern, (3) Predict the stress and strain distribution changes in the dome, (4) Identify areas of possible structural damage or failure, (5) Suggest alternatives to prevent the predicted structural damage or failure. These steps have been implemented using the fixed geometries of caverns. However, we need to consider the geometry changes of cavern due to ongoing oil sales.

Raw water must be injected through a hanging string to remove oil from one of the selected SPR caverns for the oil sale. This raw water dissolves the salt on the walls of the cavern and changes the shape of the cavern. To consider the geometry change of the oil sale cavern without changing the geometry of other caverns in the salt dome, from a perspective of finite element analysis, the stress distribution of the salt dome before the oil sale must be transferred to the mesh capturing the geometry change of the oil sale cavern. Based on the stress distribution transmitted from the time when the oil sale occurred, the change in the stress distribution around the oil sale cavern is recalculated. This calculation procedure is different from calculating based on the cavern geometry changed by the oil sale as the initial condition. This is because the current model, which calculates the changed cavern shape as an initial condition, does not reflect the change in the stress distribution due to the change in the shape of the single cavern because of the oil sale.

This letter aims to determine whether these calculation procedures can be applied to BH modeling. There are two ways to transfer the structural analysis results (distributions of stress, strain, displacement, etc.) calculated from the model before the oil sale to the newly constructed mesh capturing the cavern geometry change after the oil sale. One is to use MAPVAR and the other is to use Interpolation Transfer.

- “MAPVAR” is a computer program to transfer solution data between finite element meshes. It transfers the solution from a set of restart files of the old mesh to the new mesh [Wellman, 1999].

- "Interpolation Transfer" is a method of implementing two procedures at once in one Sierra/ADAGIO input deck. It is a technique that includes the function of MAPVAR in ADAGIO and delivers the result calculated in the first procedure to the second procedure.

During the analysis it was discovered that all combinations of interpolation options of MAPVAR with ADAGIO restart options did not produce the expected results in FY20 [Park, 2020]. That is, all transferred data such as stress and strain at every element; displacement and temperature at every node has been reset to zero during the data transfer from the donor to recipient. It is thought that the unique formulation of the SPR leaching problem, for which the mapping of different portions of the same material (in our case, salt surrounding the cavern) to different block geometries (the prescribed leach geometry of the original mesh versus the actual leached geometry in the new mesh) presents a programming challenge not considered by the HPC team that oversees MAPVAR.

In this letter, the possibility of using Interpolation Transfer rather than MAPVAR, which was used in FY20, but yielded no good results, is described. There are 14 SPR caverns in the Big Hill salt dome. The salt dome mesh has 14 cylinders for the caverns. The mesh is designed so that the cavity geometry of each cavern is placed in each cylinder. The perimeter of the cylinder encompassing each cavern consists of 36 elements, and this design is applied to all 14 caverns. When the geometry of a cavern changes due to oil sale, the cylinder mesh is recreated by placing a cavity capturing the changed geometry in the cylinder, and replacing the newly created cylinder into the cylinder hole of the cavern in the salt dome mesh. To examine the data transfer using Interpolation Transfer, the donor and recipient meshes are constructed. The meshes of donor and recipient contain the cylinder column of BH-104 in 2012 and 2018, respectively.

The calculated stress and strain data of the donor mesh in the first procedure is successfully transferred to the recipient mesh in the second procedure. We are able to provide DOE a simulation for a partial drawdown of any SPR caverns due to oil sale when requested.

Sincerely,

Byoung Yoon Park

enc: FY21 Big Hill and Bayou Choctaw Geomechanical Model Enhancements

cc: Lionel Gele, DOE
Paul Malphurs, DOE
Anna Snider Lord, SNL
Steven Sobolik, SNL
Barry Roberts, SNL
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FY21 Big Hill and Bayou Choctaw Geomechanical Models Enhancements

Milestone 1.2b1: Interpolation data transfer between the models before and after a partial drawdown leach in BH

To calculate the change in the stress distribution around a cavern which geometry is partially changed due to an oil sale, the stress distribution of the salt dome before the oil sale must be transferred to a mesh that captures the shape change of the oil sale cavern. Based on the stress distribution transmitted from the previous analysis at the time when the oil sale occurred, the stress distribution around the oil sale cavern is recalculated. To implement this, "Interpolation Transfer" in Sierra/ADAGIO is used.

Interpolation Transfers

It is sometimes desirable to chain two or more analyses (procedures) together. A common example of this is the need to preload an assembly quasistatically, then subject that assembly to a loading environment best suited to an explicit transient dynamics analysis. The displacements and stresses produced by the quasistatic preload become initial conditions for the transient dynamics event. These displacements and stresses must therefore be transferred from the initial to the subsequent analysis [SIERRA, 2019].

The inter-procedural transfers used by Adagio can transfer data from one or all blocks of the preceding or sending procedure to the subsequent or receiving procedure. The commands to control the transfers should appear at the procedure scope in the receiving procedure. When using inter-procedural transfers, irrespective of the transfer type chosen, all global variables are copied by default from the sending procedure to the receiving procedure, and all appropriate element data is transferred from the sending to the receiving elements. Nodal data is transferred based on the type of analysis done in the two procedures.

Interpolation Transfer is a method of calculating two procedures at once in one Sierra/ADAGIO input deck. It is a technique that includes the function of MAPVAR in

ADAGIO and delivers the result calculated in the first procedure to the second procedure.

Model Description

The numerical analysis model, which consists of a realistic mesh capturing the geometries of the Big Hill SPR site and M-D salt creep, has been upgraded. Figure 1 shows the 2020 version of hexahedral finite element mesh with the Exodus II format of 344 MB file size. The surrounding rock block encircles the caprock and salt dome blocks. The major fault (shear zone) is included in this model to perhaps better represent the large-scale deformation considered in this study. The lengths of the confining boundaries are 14,600 ft in the N-S direction and 12,400 ft in the E-W direction, and extending vertically from the ground surface down to the depth of 6000 ft. The entire mesh consists of 4,467,084 nodes and 4,439,700 elements with 366 element blocks, 3 node sets (on the boundaries of the entire mesh, to enforce zero normal displacement boundary conditions), and 84 side sets (on the interior surfaces of the caverns and skin layers, to enforce cavern pressure boundary conditions). Running ADAGIO using the daily wellhead pressure data and oil-brine interface depth obtained from the field office was performed from 1/1/1900 to 7/16/2015 when the oil sale is assumed to have occurred. All runs were performed with ADAGIO Version 4.58.2 (or daily version) using 1024 cores (processors) on SKYBRIDGE in Sandia's High-Performance Computer (HPC) systems.

Table 1 lists the elevations of cavern top and bottom, cavern volumes in the mesh with the dates when the sonar data were obtained. The modeling simulates the cavern responses forward in time from the cavern's initial creation. The real wellhead histories of 14 caverns have been recorded from the dates as listed in Table 2. For the purposes of the present simulation, it is assumed that the initial leaches of the caverns started on the dates one year before the wellhead pressure recording started, i.e. they were leached to full size over a one-year period. Before initial leaching of a cavern starts, the model is given a stabilization period (1/1/1900 – 4/20/1989). To avoid the numerical shock, gravity is applied gradually into the mesh for ten seconds. After that, the model is allowed to consolidate with gravity for 89 years so that every element is stabilized numerically. The analysis simulates caverns that were leached to full size over a one-year period by means of gradually switching from salt to brine in the caverns. It is assumed that the SPR caverns were filled with petroleum and brine after the initial leaching (on 4/20/1990) [Park, 2019]. Creep is then permitted to occur over the entire simulation period.

There is no sonar data on the date of initial leach completion of each cavern. There were several times of raw water injections for each cavern lifetime. Each raw water injection increases the cavern volume since the injected water dissolves the salt on the cavern wall. The FE computational model in this study cannot consider the cavern volumetric change due to the small amount of injected raw water. For the simplification, the initial volume of each cavern on 4/20/1990 is assumed to be the cavern volume in Table 1 even though the volumes are not that were measured on the date of initial leach completion.

BH-104 was selected to consider the geometry change of the cavern due to oil sale as an example test. Sonar surveys for BH-104 were conducted in 2012 and 2018. The cavern volume was measured to be 13.28 MMB and 14.04 MMB in 2012 and 2018, respectively, as listed in Table 1. Figure 2 shows the geometry change of BH-104 due to oil sale. As we can see, the diameter of the lower part of the cavern increased in 2018 compared to 2012. The mesh containing BH-104 in 2018 is rebuilt. The numbers of nodes and elements of the entire mesh are changed to 4,461,967 and 4,434,600, respectively. To withdraw the oil from the cavern, raw water is injected into the bottom of the cavern through a hanging string. This water pushes up the oil, and then the oil comes out through a valve on the ground. This injected water dissolves the walls of the cavern, so the diameter of the lower cavern increases.

There are 14 SPR caverns in the Big Hill salt dome. The salt dome mesh has 14 cylinders for the caverns as shown in Figure 2. The mesh is designed so that the cavity geometry of each cavern is placed in each cylinder. The perimeter of the cylinder encompassing each cavern consists of 36 elements, and this design is applied to all 14 caverns. When the geometry of a cavern changes due to oil sale, the cylinder mesh is recreated by placing a cavity capturing the changed geometry in the cylinder, and replace the newly created cylinder into the cylinder hole of the cavern in the salt dome mesh.

Modeling of the leaching process of the caverns is performed by deleting a pre-meshed layer of elements along the walls of the cavern so that the cavern volume is increased by 16 percent per drawdown. Figure 2 shows the cavern cavities of BH-104 in 2012 and 2018 as developed from sonar data, along with drawdown layers (leaching onion skins) and extra layers. In this simulation, 14 SPR caverns are modeled as having five drawdown layers to be removed to account for the future oil full (not partial) drawdown activities.

In this report, it is assumed that the shape of the other surrounding caverns have not changed, but only the geometry of BH-104 changed, and the geometry change is assumed to occur on 7/16/2015 which is the assumed date of the oil sale from BH-104.

To calculate the change in the stress distribution around the cavern caused by an oil sale, the changes in the shape and internal pressure of the BH-104 before and after the oil sale occurs is considered. The stress distribution in the salt dome containing 14 caverns are calculated from 4/20/1990 (simulation start date) to 7/16/2015 in Procedure_1 in Sierra/Adagio input deck. To consider the geometry change of BH-104, the simulation should be restarted on the date of oil sale (the withdrawal of amount of oil is assumed to complete in a day) with the newly constructed mesh whose cavity in 2012 is replaced with that in 2018 in the BH-104 cylinder. At the same time, the analysis results on 7/16/2015 must be transferred to the newly created mesh. The analysis results mean that stress and strain of every element with displacement and temperature of every node on 7/16/2015. And then, the simulation restarts using this mesh at the date of interest (7/16/2015 in this case).

"Interpolation Transfer" in Sierra/Adagio is used as a tool for transferring the stress and strain distribution and the deformed caverns on 7/16/2015. The structure of input deck for this example test is listed in Appendix A.

Table 1. Sonar survey dates, elevations of cavern tops and bottoms, and cavern volumes in the mesh

Cavern ID	Sonar Survey Date	Top Elevation (ft)	Bottom Elevation (ft)	Volumes in the Mesh (MMB)	Volumes in the Mesh (ft^3)
BH-101	09/11/2012	-2240	-4120	14.14	79,398,740
BH-102	08/29/2013	-2280	-4020	12.40	69,604,013
BH-103	10/04/2011	-2260	-3820	12.41	69,664,667
BH-104	05/02/2012	-2260	-4160	13.28	74,541,296
BH-104	04/17/2018	-2260	-4160	14.04	78,805,552

Cavern ID	Sonar Survey Date	Top Elevation (ft)	Bottom Elevation (ft)	Volumes in the Mesh	
				(MMB)	(ft^3)
BH-105	07/16/2013	-2260	-3960	12.92	72,528,615
BH-106	03/31/2015	-2280	-4060	12.53	70,348,964
BH-107	09/17/2019	-2240	-4040	11.91	66,886,820
BH-108	12/17/2019	-2320	-4060	10.77	60,482,152
BH-109	02/10/2020	-2260	-4140	12.28	68,955,817
BH-110	03/23/2020	-2260	-4140	12.09	67,880,161
BH-111	04/29/2015	-2240	-4200	13.16	73,909,534
BH-112	05/07/2015	-2280	-4180	12.55	70,483,655
BH-113	09/24/2015	-2260	-4120	11.72	65,808,317
BH-114	10/24/2013	-2320	-4100	12.41	69,687,984

Table 2. Dates of initial leach completion, wellhead pressure recording started, and assumed initial leach started [Park, 2019]

Cavern ID	Date of Initial Leach Completion	Date of Wellhead Pressure Recording Started	Assumed Date Initial Leach Started
BH101	09/17/1990	09/19/1990	09/19/1989
BH102	10/19/1990	10/20/1990	10/20/1989
BH103	11/27/1990	11/29/1990	11/29/1989
BH104	10/21/1990	10/21/1990	10/21/1989
BH105	05/13/1990	05/14/1990	05/14/1989
BH106	10/15/1990	10/17/1990	10/17/1989
BH107	04/23/1990	04/25/1990	04/25/1989
BH108	06/13/1990	06/14/1990	06/14/1989
BH109	07/23/1990	07/25/1990	07/25/1989
BH110	04/18/1990	04/20/1990	04/20/1989
BH111	07/14/1991	07/15/1991	07/15/1990
BH112	06/17/1991	06/19/1991	06/19/1990
BH113	04/30/1991	05/02/1991	05/02/1990
BH114	08/26/1991	08/29/1991	08/29/1990

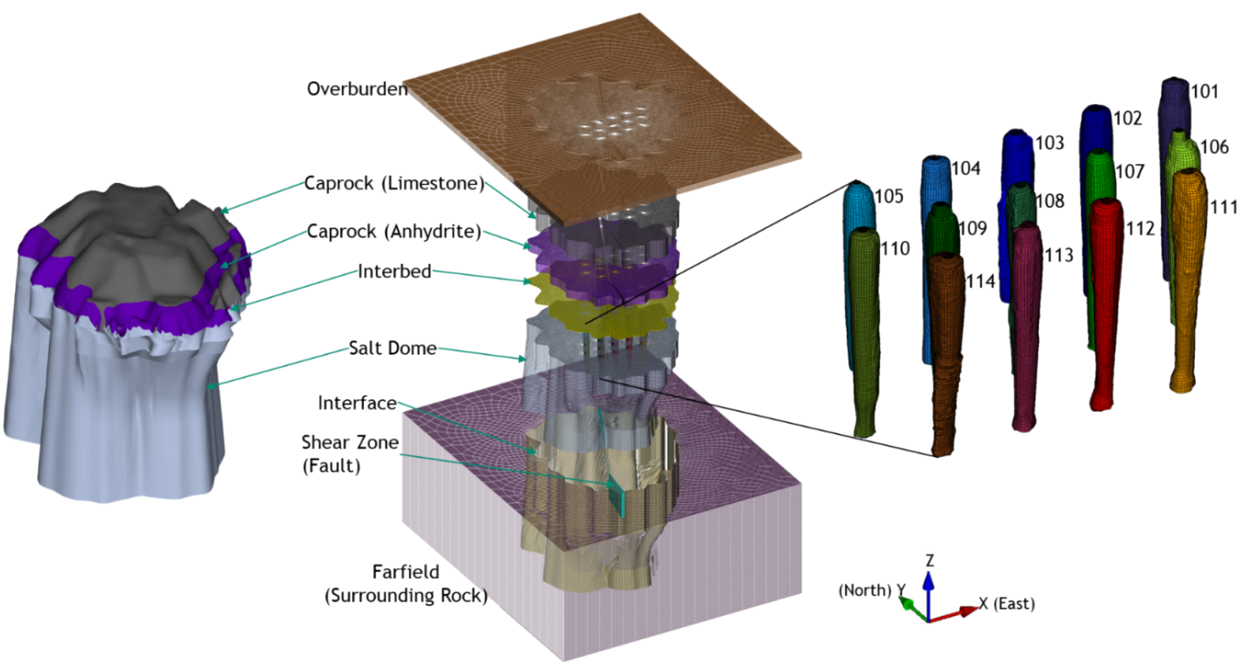

Figure 1. Images of Big Hill salt dome and caprock obtained from the seismic, sonar and borehole survey (left), an overview of the meshes of the stratigraphy (middle), and caverns (right). The cavern ID numbers are also shown. The US Patent (Number: 10657301, Grant date: 5/19/2020) is applied to create the mesh.

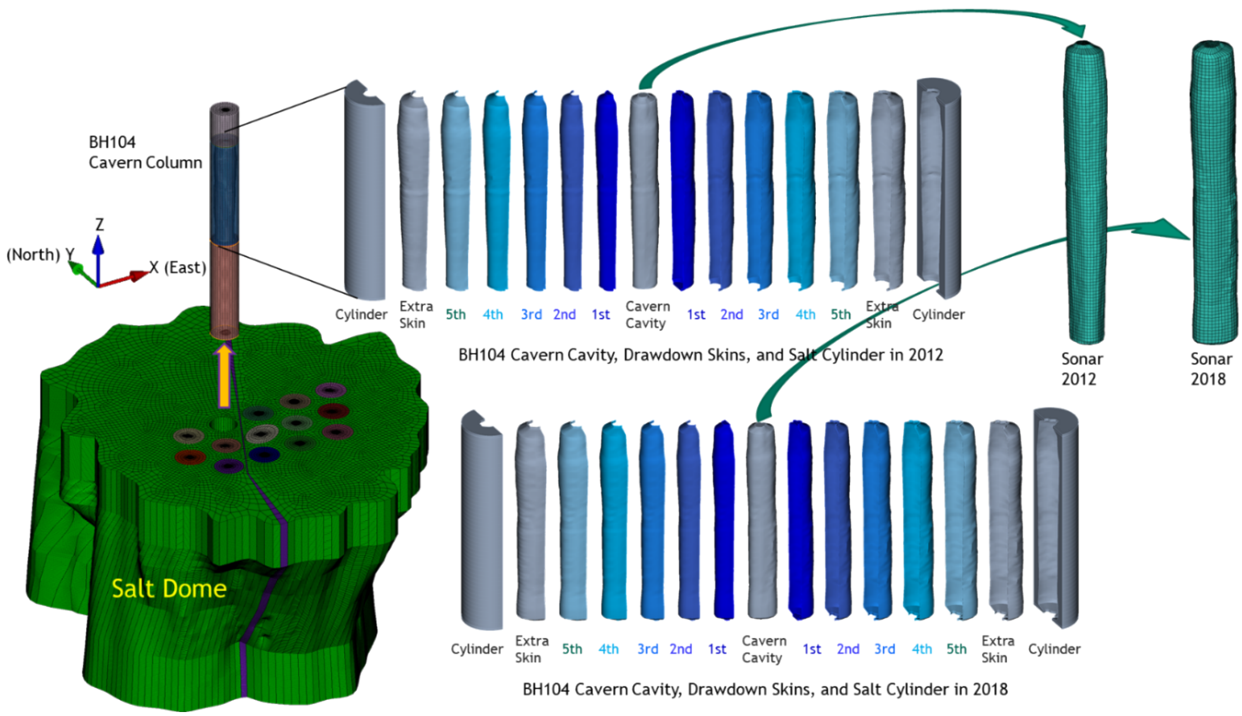

Figure 2.Geometries of BH-104 in 2012 and 2018. The salt dome has 14 cylinders. The cavity of each cavern is placed in each cylinder cavern column. The perimeter of the cylinder surrounding each cavern consists of 36 elements, and this design is applied to all 14 caverns.

Analysis Results

To examine the data transferring using Interpolation Transfer, the donor and recipient meshes were constructed. The meshes of donor and recipient contain the cylinder column of BH-104 in 2012 and 2018, respectively, as shown in Figure 2.

Figure 3 shows the predicted volumetric changes of BC-104 and neighboring caverns over time. The values of cavern volumes on the beginning (1/1/1900) are the same as listed in Table 1. The mesh volume of BH-104 is reduced from 13.28 MMB on 1/1/1900 to 13.21 MMB on 9/28/1990 due to consolidation by gravity. The cavern volumes decrease with time due to salt creep closure. The rapid closure rate (stair shapes) in each curve indicates the volume closures during the workover period which internal pressures are lower than that during the normal operation. The cavern volume of BH-104 before the oil sale on 7/16/2015 is calculated to be 12.50 MMB.

The mesh volume of BH-104 after the oil sale assumed to be 14.04 MMB as listed in Table 1, because the sonar volume on 4/17/2018 is assumed as the cavern volume after the oil sale. The cavern volume after the oil sale on 7/16/2015 is calculated to be 13.26

MMB (not 14.04 MMB) because the displacement data at every node in the mesh is transferred from the donor to the recipient.

Figure 4 and 5 show the contour plots of principal stress (σ_1) and principal strain (ε_1), respectively, on the salt domes of donor (left) and recipient (right) meshes on 7/16/2015. The σ_1 and ε_1 distributions on both domes are the same exactly, i.e. the calculated stress and strain data of the donor on 7/16/2015 is successfully transferred to the recipient.

It is important to validate that the interpolation transfer scheme does two things correctly: calculates expected values of the stresses and strains around modified cavern BH-104 from the old mesh to the new mesh; and transfers the same stress and strain fields around the other caverns (and in particular the caverns closest to BH-104). Figure 6 shows the contour plots of principal stress (σ_1) on donor and recipient meshes of BH-103 (left two panels) and BH-105 (right two panels) on 7/16/2015, respectively. The σ_1 distributions on both meshes of BH-103 and BH-105 are the same exactly, i.e. the calculated stress data of the donor of BH-103 and BH-105 on 7/16/2015 is successfully transferred to the recipient meshes. The contour plots of σ_1 on donor and recipient meshes of BH-104 (two panels in middle) on 7/16/2015 are also shown. The σ_1 distributions on both meshes of BH-104 are not the same because of the lower part of the BH-104 cavern that has been enlarged due to oil sale. The distributions on the upper cavern are close each other, but on the lower cavern are not the same. The calculated stress data of the donor of the lower part of BH-104 on 7/16/2015 are successfully transferred to the recipient mesh, thus the stress distributions in both meshes look similar. This means that this provides a starting point from which to start the new calculations with the new geometry. Because the new cavern geometry is different, the stress field will immediately begin adjusting from the transferred states. The neighboring caverns BH-103 and BH-105 are selected to compare the interpolation transfer results with BH-104.

Figure 7 shows the contour plots of principal strain (ε_1) on donor and recipient meshes of BH-103 (left two panels), BH-104 (middle two panels), and BH-105 (right two panels) on 7/16/2015, respectively. As the same reasons of the stress distribution above, the calculated strain data of the donor of BH-104 on 7/16/2015 are successfully transferred to the recipient mesh.

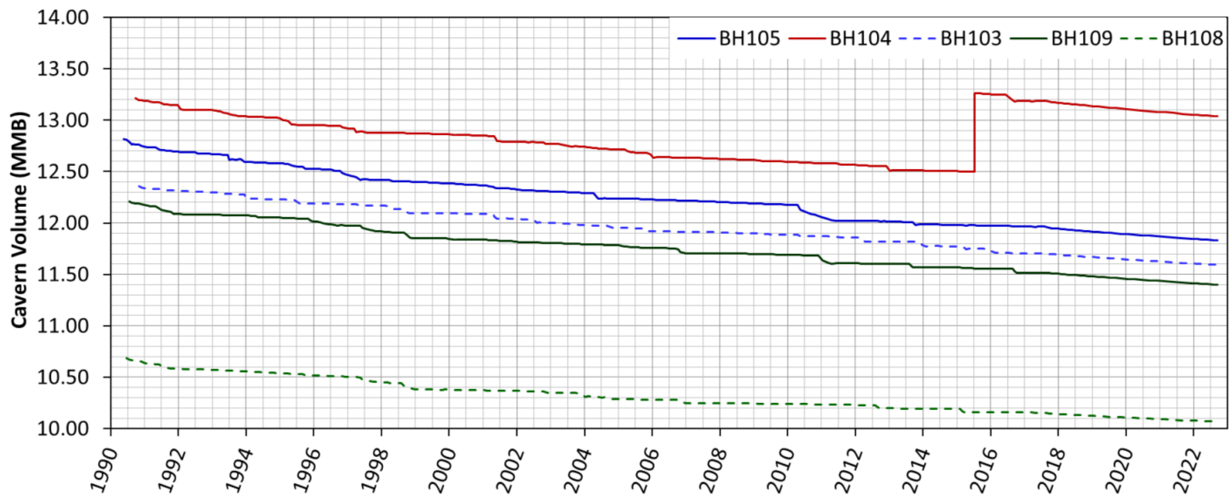

Figure 3. Predicted individual cavern volumetric change over time. Each number at the beginning and ending of curves indicates each cavern volume on 4/20/1990 and 7/31/2015, respectively.

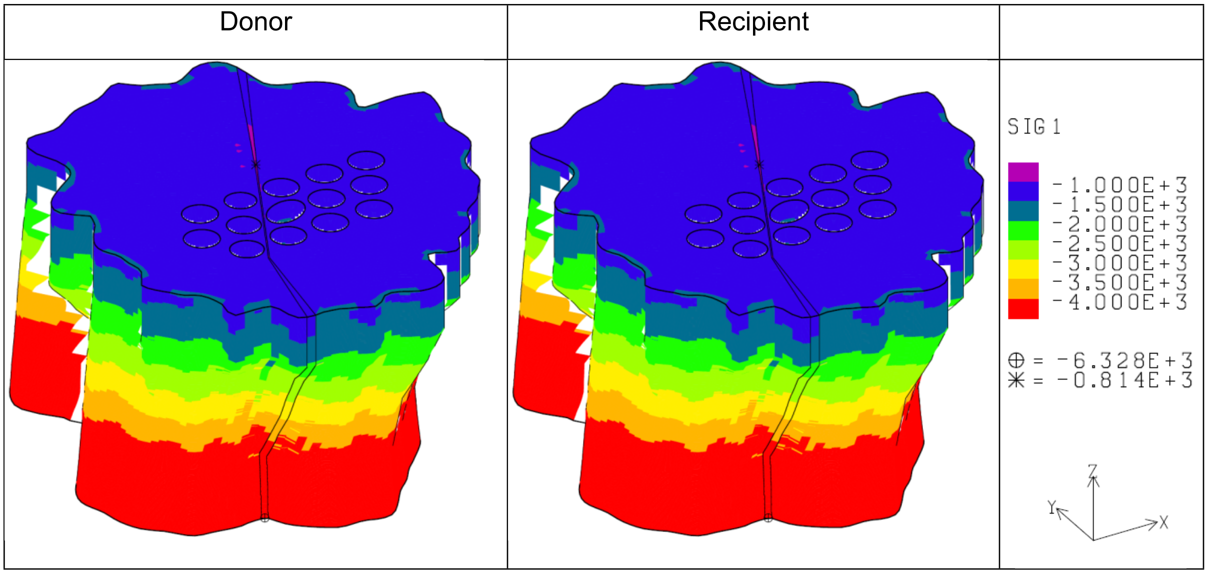

Figure 4. Contour plots of principal stress (σ_1) on the salt domes of donor (left) and recipient (right) meshes on 7/16/2015. The σ_1 distributions on both domes are the same exactly i.e., the calculated stress data of the donor on 7/16/2015 is successfully transferred to the recipient mesh.

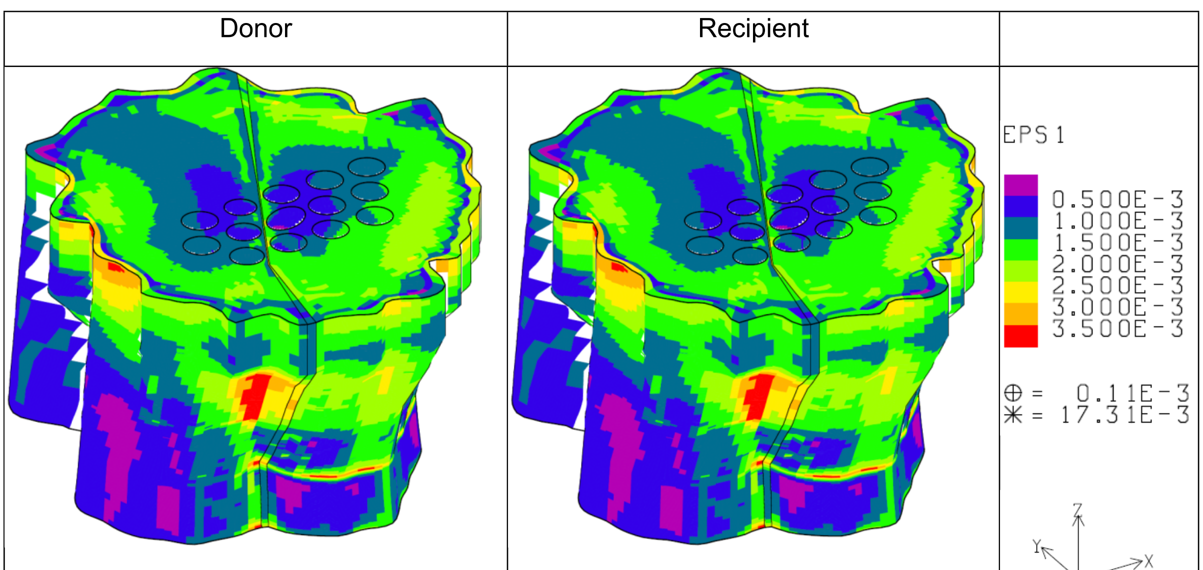

Figure 5. Contour plots of principal strain (ε_1) on the salt domes of donor (left) and recipient (right) meshes on 7/16/2015. The ε_1 distributions on both domes are the same exactly i.e., the calculated strain data of the donor on 7/16/2015 is successfully transferred to the recipient mesh.

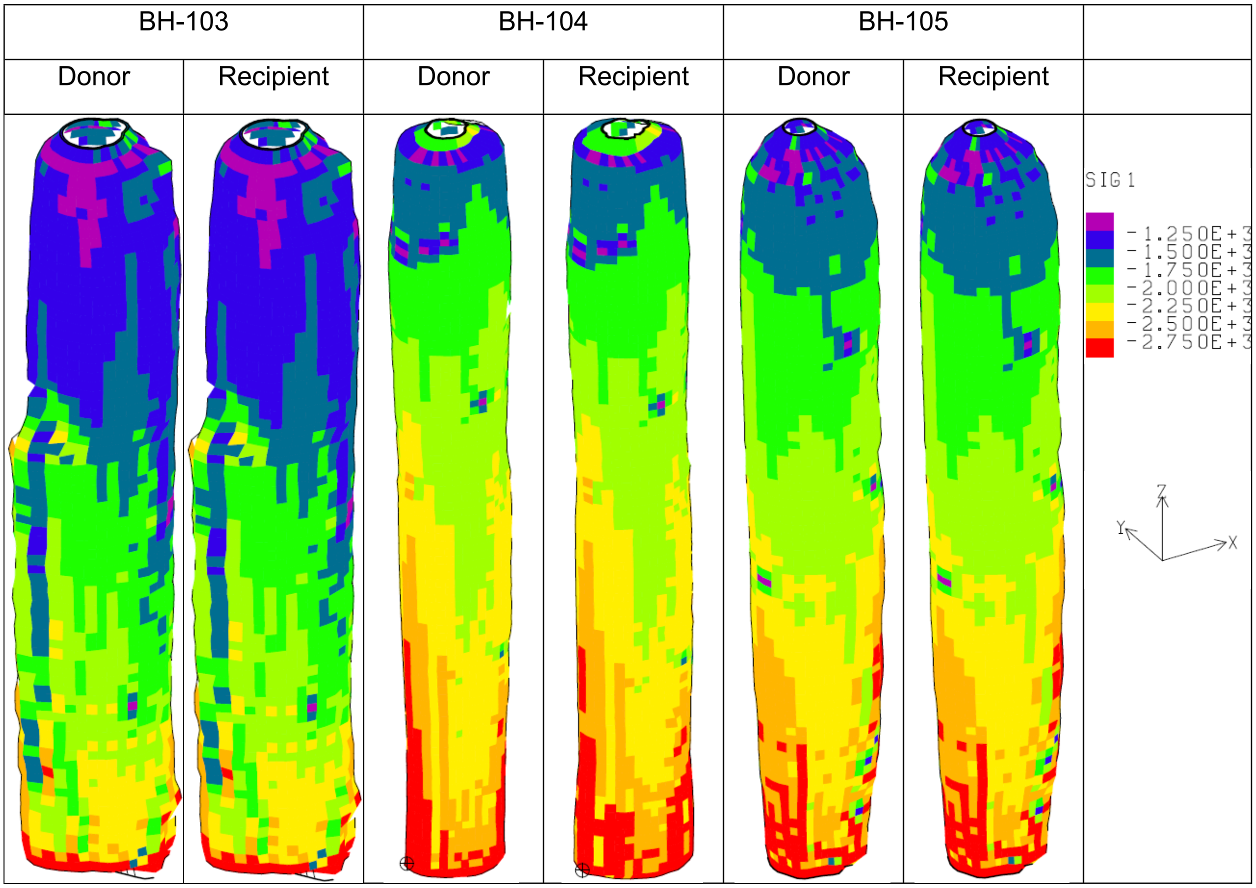

Figure 6. Contour plots of principal stress (σ_1) on donor and recipient meshes of BH-103 (left two panels) and BH-105 (right two panels) on 7/16/2015, respectively. The σ_1 distributions on each donor and recipient meshes of BH-103 and BH-105 are the same exactly i.e., the calculated stress data of the donor of BH-103 and BH-105 on 7/16/2015 is successfully transferred to the recipient meshes. Contour plots of σ_1 on donor and recipient meshes of BH-104 (two panels in middle) on 7/16/2015. The σ_1 distributions on each cavern mesh of BH-104 are not the same. However, the calculated stress data of the donor of the lower part of BH-104 on 7/16/2015 seems to be successfully transferred to the recipient mesh, because the stress distribution in both meshes are similar.

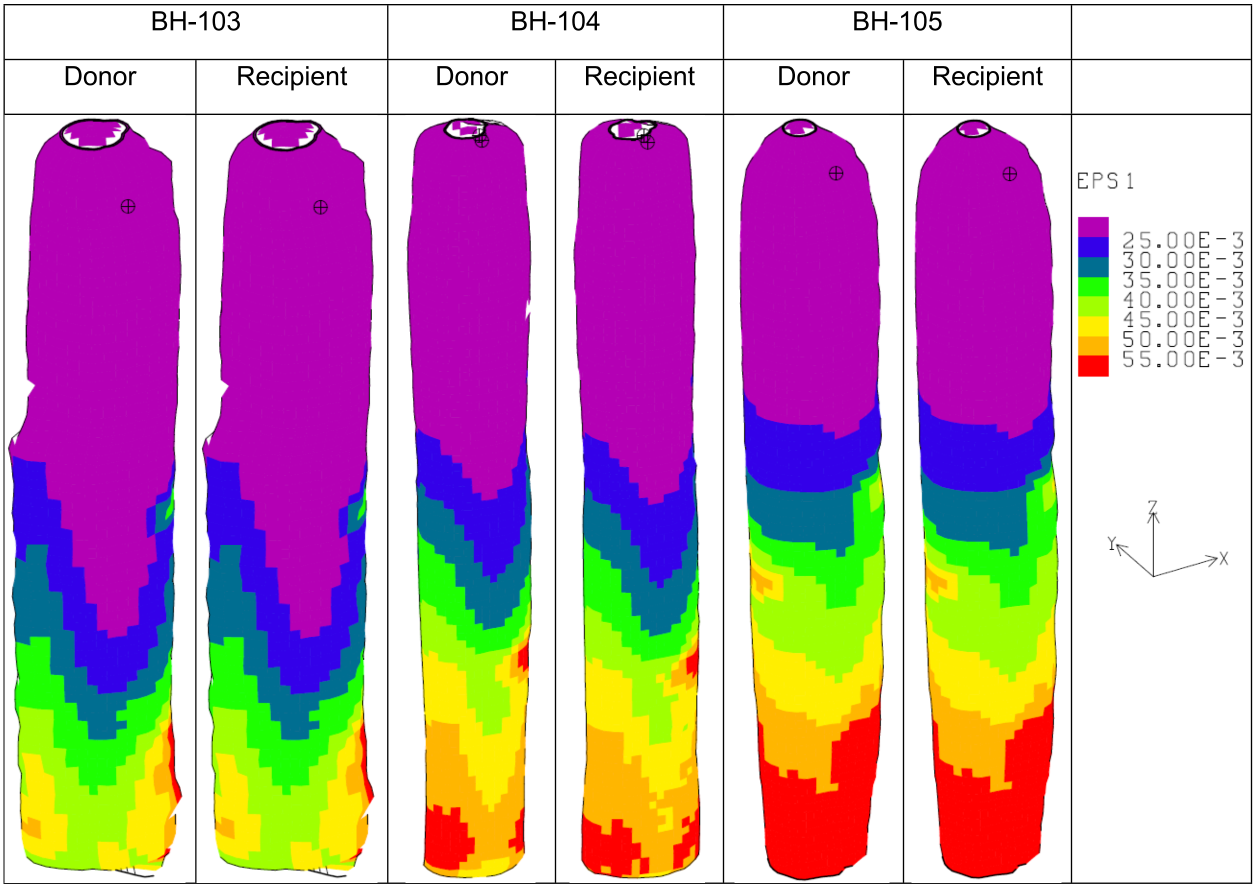

Figure 7. Contour plots of principal strain (ε_1) on donor and recipient meshes of BH-103 (left two panels) and BH-105 (right two panels) on 7/16/2015, respectively. The ε_1 distributions on both meshes of BH-103 and BH-105 are the same exactly i.e., the calculated stress data of the donor of BH-103 and BH-105 on 7/16/2015 is successfully transferred to the recipient meshes. Contour plots of ε_1 on donor and recipient meshes of BH-104 (two panels in middle) on 7/31/2015. The ε_1 distributions on both meshes of BH-104 are not the same. The distributions on the upper cavern are close each other, but on the lower cavern are not the same. However, the calculated strain data of the donor of the lower part of BH-104 on 7/16/2015 seems to be successfully transferred to the recipient mesh, because the strain distribution in both meshes are similar.

Conclusions

In the SPR simulation so far, a mesh was constructed based on the latest sonar survey data of each cavern, and the change in volume due to salt creep was calculated by applying the internal pressure change to the inner surface of the cavern. The structural integrity of the cavern was calculated by calculating the stress distribution around the cavern reflecting the internal pressure change with cavern volume change due to salt creep.

Nowadays, with the mandated oil sales, it is necessary to calculate the change in the stress distribution of the salt dome due to the geometry change of one cavern caused by the oil sale. To consider the geometry change of the oil sale cavern without changing the geometry of other caverns in the salt dome, from a perspective of finite element analysis, the stress distribution of the salt dome before the oil sale must be transferred to the mesh capturing the geometry change of the oil sale cavern. Based on the stress distribution transmitted from the time when the oil sale occurred, the change in the stress distribution around the oil sale cavern is recalculated. This calculation procedure is different from calculating based on the cavern geometry changed by the oil sale as the initial condition. This is because the current model, which calculates the changed cavern shape as an initial condition, does not reflect the change in the stress distribution due to the change in the shape of the single cavern because of the oil sale.

This letter aims to determine whether these calculation procedures can be applied to Big Hill and Bayou Choctaw modeling. There are two ways to transfer the structural analysis results (distributions of stress, strain, displacement, etc.) calculated from the model before the oil cell to the newly constructed mesh capturing the cavern geometry change after the oil sale. One is to use MAPVAR and the other is to use Interpolation Transfer. Interpolation transfer is a method of calculating two procedures at once in one Sierra/ADAGIO input deck. It is a technique that includes the function of MAPVAR in ADAGIO and delivers the result calculated in the first procedure to the second procedure. I tried this method as in the ADAGIO Manual with the Sandia High Performance Computer (HPC) team help. The calculation has been completed successfully.

There are 14 SPR caverns in the Big Hill salt dome. The salt dome has 14 cylinders for the caverns. The mesh is designed so that the cavity geometry of each cavern is placed in each cylinder. When the geometry of a cavern changes due to oil sale, the cylinder mesh is recreated by placing a cavity capturing the changed geometry in the cylinder, and replace the newly created cylinder into the cylinder hole of the cavern in the salt dome mesh. To examine the data transferring using Interpolation Transfer, the donor and recipient meshes are constructed. The donor and recipient meshes contain the cylinder column of BH-104 in 2012 and 2018, respectively.

The stress, strain, and displacement distributions on both meshes of donor and recipient except the cylinder column of BH-104 are the same exactly. The stress and strain distributions on the meshes of BH-104 before and after the oil sale, respectively, are not the same because of the lower part of the BH-104 cavern that has been enlarged due to oil sale. The distributions on the upper cavern are close each other, but on the lower cavern are not the same. However, the calculated stress data of the donor of the lower part of BH-104 on 7/16/2015 are successfully transferred to the recipient mesh, because the stress distribution in both meshes are similar, i.e. the calculated stress and strain data of the donor on 7/16/2015 from the first procedure (performed from 1/1/1900 to 7/15/2015) is successfully transferred to the recipient in the second procedure. We are able to provide DOE a simulation for a partial drawdown of any SPR caverns due to oil sale when requested.

Acknowledgments

The author would like to thank Steven R. Sobolik and Anna C. Snider Lord of Sandia provided technical review and valuable comments. Sandia department manager Donald Conley and SPR project manager Anna C. Snider Lord who supported this work. As always, the support of Diane Willard and Paul Malphurs of DOE are greatly appreciated. This report has been improved by these individuals.

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Appendix A

```
begin sierra model_name

  title SPR Big Hill, model_name, RF=1 A1F=1 A2F=1 K0F=1 K1F=1 TS=1d

# Define the file name containing the Fortran 77 user subroutine
  user subroutine file = surbroutine_name.F

  define direction y with vector 0.0 1.0 0.0
  define direction x with vector 1.0 0.0 0.0
  define direction z with vector 0.0 0.0 1.0
  define direction negative_z with vector 0.0 0.0 -1.0
  define point origin with coordinates 0.0 0.0 0.0

  #---------- Functions ---------

  # ASCENDING ORDER IS REQUIRED FOR DEFINING FUNCTION
  begin definition for function function_1  # Gravity

        ...

  end definition for function function_1

  #---------- Materials ----------

  begin property specification for material mat_1 # Salt dome (salt)

        ...

  end property specification for material mat_1

  begin solid section solid_1

        ...

  end solid section solid_1

#================= Finite Element Model ==================================


  begin finite element model model_name

    Database name = 1st_mesh_2012.g
    Database type = exodusII

    begin parameters for block block_1
        ...
    end parameters for block block_1


        ...

  end finite element model model_name

 #================== ADAGIO PROCEDURE ====================================================
  begin adagio procedure procedure_1

    #---------- Time Step Control ----------

    begin time control

        ...

    end time control

    begin adagio region region_1

      use finite element model model_name

      #--------- Boundary Conditions ---------

      begin gravity

        ...

      end gravity

      begin prescribed temperature
```

```
   ...
end prescribed temperature
begin fixed displacement # East-West sides
   ...
end fixed displacement
begin fixed displacement # North-South sides
   ...
end fixed displacement
begin fixed displacement # Bottom of model
   ...
end fixed displacement

begin pressure # pressure in cavern
   ...
end pressure
#--------- Element Death --------------
begin element death leach_101  # Initial leach starts at BH101
   ...
end element death leach_101
   ...
#--------- Initial Conditions ---------
begin initial condition # Salt dome
   ...
end initial condition

#--------- Results Output ---------
begin results output output_1
   ...
end results output output_1
#--------- Restart ---------
begin restart data restart_1
   ...
end restart data restart_1
#--------- Solver ---------
begin adaptive time stepping
   ...
end adaptive time stepping
begin solver  # implicit only
##
  begin loadstep predictor
   ...
  end loadstep predictor
  begin cg
```

```
        ...

      end cg
    end solver  # implicit only
  end adagio region region_1

 end adagio procedure procedure_1

#========Procedural Transfers ==============================

 begin finite element model model_name_2018

  Database name = 2nd_mesh_2018.g
  Database type = exodusII

  begin parameters for block block_1

        ...

  end parameters for block block_1


        ...


 end finite element model model_name_2018

#-------- PROCEDURE 2 ---------------------------------------------------------------

 begin adagio procedure procedure_2

  begin procedural transfer trans_104
    begin interpolation transfer
      SEND BLOCKS = block_1 block_2 block_3 block_4 block_5 block_8 \#

        ...

      nearest element copy
      block by block
    end interpolation transfer
  end procedural transfer trans_104

  #---------- Time Step Control ----------

  begin time control

        ...


  end time control

  begin adagio region region_2

    use finite element model model_name_2018

    #--------- Boundary Conditions ---------

    begin gravity

        ...

    end gravity

    begin prescribed temperature

        ...

    end prescribed temperature

    begin fixed displacement # East-West sides

        ...

    end fixed displacement

    begin fixed displacement # North-South sides

        ...

    end fixed displacement
```

```
     begin fixed displacement # Bottom of model
       ...
     end fixed displacement
     begin pressure # pressure in cavern
       ...
     end pressure
     #--------- Element Death --------------
     begin element death leach_proc2  # remove cavities as soon as procedure_2 starts
       ...
     end element death leach_proc2
     #--------- Results Output ---------
     begin results output output_2
       ...
     end results output output_2
     #--------- Restart ---------
     begin restart data restart_2
       ...
     end restart data restart_2
     #--------- Solver ---------
     begin adaptive time stepping
       ...
     end adaptive time stepping
     begin solver  # implicit only
##
      begin loadstep predictor
       ...
      end loadstep predictor
      begin cg
       ...
      end cg
     end solver  # implicit only
   end adagio region region_2
  end adagio procedure procedure_2
end sierra model_name
```

References

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