

Geomechanical Optimization of Underground Gas Storage Operation

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Abstract: *The case study endeavors to optimize the operation conditions of an underground gas storage (UGS) facility that uses a depleted gas field for storage. During the production of the field, some seismic events were registered in a region considered a low seismicity area; therefore, it was concluded that the seismicity was induced by the depletion of the reservoir. A characteristic feature of the field is a mid-field fault, which terminates in the center of the reservoir. Using seismic analyses, it was determined that the most logical positions of the seismic events were on the mid-field fault. Considering the large amount of depletion (20 MPa) the field has experienced in the past and the historical seismic events, a study was initiated to optimize the dynamic storage operations under consideration of geomechanical aspects.*

The paper presents the workflow used to assess fault slip risk during the UGS operation. The workflow starts with the construction of a 3D finite element model of the complex geology using Abaqus and is followed by coupling it to a reservoir flow model of the field. The results show that a strong pressure gradient in the field is one of the factors which impact the fault stability. Therefore, a balanced reservoir model is developed to control pressure on both sides of the fault. This model minimizes the risk of fault re-activation. A Monte Carlo simulation on the fault slip stability is performed to quantify the reliability of the prediction.

A multidisciplinary team was formed to undertake the project's sub-surface challenges. Several UGS operation scenarios were modeled in an iterative manner to derive the operating conditions which minimize the fault slip risk while maintaining economic viability. The result is an UGS operational plan which is not only controlled by reservoir engineering, but strongly guided by the geomechanical finite element modeling.

Keywords: 3D Geomechanics, Coupled Analysis, Fault Stability.

1. Introduction

During production of the gas field in the study, two pairs of seismic events were registered. The earthquakes caused slight damage to property such as housing. Because the region is assumed to be a low tectonic seismicity area, the seismicity was likely induced by the depletion of the gas field.

Seismic analysis projected the induced seismic events as occurring on the central fault in the gas field. Given the earthquake risk associated with the operation of an underground gas storage in a field with a history of induced earthquakes, an investigation of the effects of dynamic storage operations (injection/production cycles) on the stability of the central fault is necessary. Additional knowledge will ultimately reduce the risk of induced earthquakes.

1.1 Objectives

The primary objective is to improve the understanding of the geomechanical processes that are linked to the stability of the reservoir and central fault during underground gas storage operation. Specifically, the objective is to review the effect of different injection and production rates on the central fault stability and the associated seismic response of the reservoir.

2. Method

The workflow for the project can be divided into 6 main steps:

1. Construct the structural geological model for the field.
2. Generate a 3D finite element model from the structural model.
3. Determine the initial stress state by building 1D geomechanical models for the wells in the study field.
4. Populate the finite element mesh with mechanical properties and pore pressures.
5. Run a finite element calculation of stress changes due to modelled pore pressure and temperature changes.
6. Assess fault stability using the calculated stresses.

2.1 Structural model

The first step in the workflow is setting up the 3D structural model which is the basis for the 3D finite element model. The structural model is based on structural depth information gathered through 3D seismic. In the case study, the commercially available program JewelSuite is used to create 3D surfaces from the 3D seismic data. The constructed surfaces are compared with the formation tops available in the well data to assure that the generated structure fits all available data. Since reservoir simulation results are used to populate the pore pressure in the reservoir in step 4, care was taken that the structural model follows the reservoir model as accurately as possible.

An important part of constructing a valid structural model for generating the finite element model is honoring all surface contacts. Each surface must have a perfect or “water-tight” contact, which means that no gaps are allowed at the intersections. The perfect fit between the surfaces is necessary to define a formation by an enclosed volume and to be able to apply material properties per formation in the finite element model.

Figure 1 shows the cross-section of the final model. The characteristics of the structure are the large listric fault which dies out on top of the Zechstein salt formation and the central fault in the reservoir. The Zechstein salt formation is continuous over the field and decouples the clastic overburden from the Platten Dolomite and the reservoir below. The central fault in the reservoir is indicated with MFF in Figure 1 on which the seismic events were located during the production of the field.

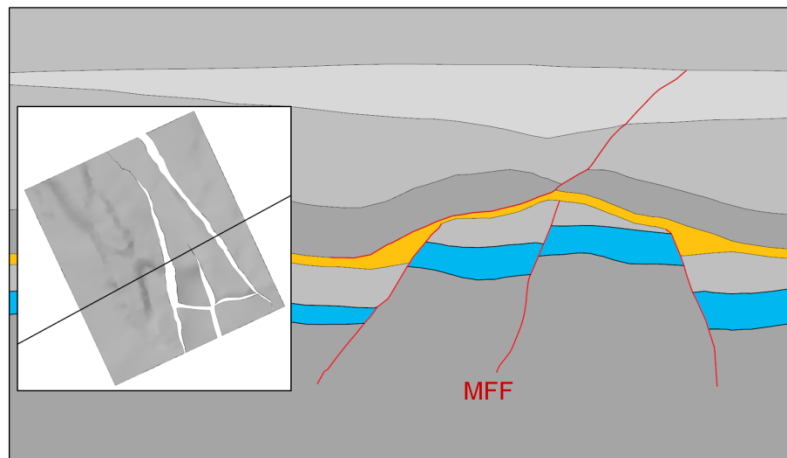


Figure 1. Final structural model of the studied field. Inset shows the location of the cross- section. The Zechstein salt layer is drawn in orange. The reservoir layer is displayed in blue. MFF indicates the central fault.

2.2 Generating 3D Finite Element Mesh

The next step of the process is translating the structural model, which consists only of surfaces, into a solid 3D finite element model. The 3D mesh building is fully automated and started from JewelSuite. The actual mesh building is performed in Abaqus/CAE using a proprietary Python script. Details about the mesh building can be found in van der Zee et al. (2011).

Every layer in the structural model results in a separate layer/volume in the finite element model. The mesh building routines allow determining an area of interest where the mesh is built in high detail. In the case of the studied field an area in the reservoir near the central fault termination was chosen to meshed with a high resolution (Figure 2) since this is the area which was probably the source of the seismicity in the earthquakes.

All faults in the structural model are represented geometrically. It was decided to make the model as one continuum, and not introducing contact surfaces into the model; this has several advantages and disadvantages.

Advantages:

When the fault separates two reservoir units with different pore pressures, it is geologically unknown which of the pore pressures is present in the fault at the slip surface (Figure 3). Several options are possible; it can be the highest pore pressure, the lowest or the pressure of one side of the fault. As an intermediate possibility an average of both sides of the fault can be used. Since the pore pressure distribution east and west of the fault is varying in time it can lead to many different scenarios for the fault stability calculations. With a fixed fault, all the scenarios can be examined analytically after the total stress state is calculated with the finite element model.

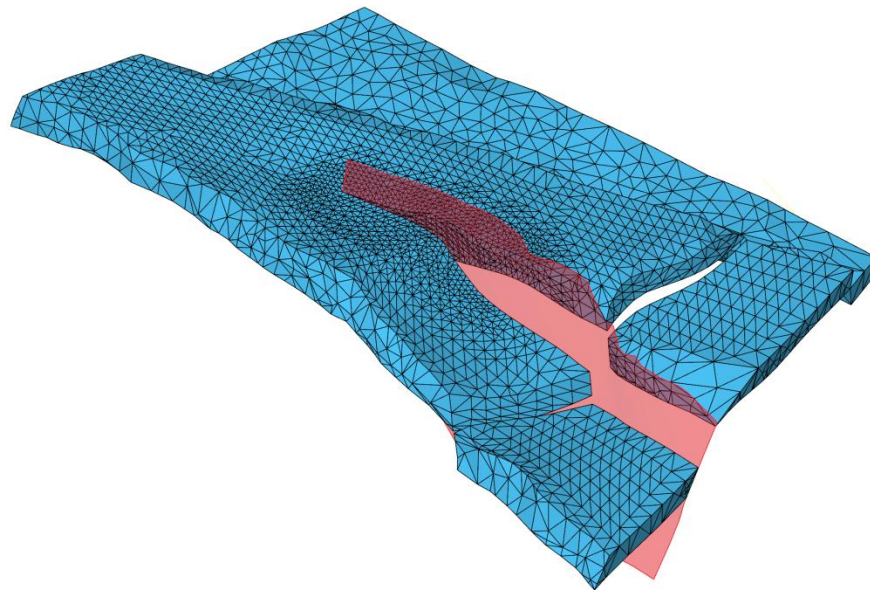


Figure 2. Detail of the reservoir layer with the (transparent) central fault. Note the mesh concentration near the fault termination for detailed results in this area.

Another advantage of using a fixed fault in the model is that the effect of the sliding friction coefficient can be examined analytically after running the finite element model. The sliding friction coefficient has a significant effect on the stability of the fault. If the friction coefficient on a sliding fault is incorporated in the finite element model, then the calculated stress field is influenced by this coefficient. Therefore, it is impossible to estimate the effect of the friction coefficient without running several scenarios, one for each friction coefficient. Fixing the fault in the finite element model enables for a sensitivity analyses to be run on pore pressure and friction coefficient using the total stresses calculated in the model without running an unrealistic amount of analyses.

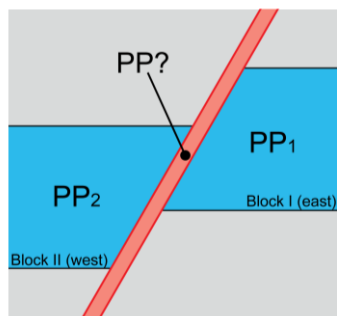


Figure 3. Illustration of the issues with defining the pore pressure in the fault zone.

Disadvantages:

Fixing the faults in the finite element model also has some disadvantages. The largest disadvantage is that stress relaxation due to (seismic) slip is not calculated. Two earthquakes occurred during the production of the field. During these slip events stress is released, which cannot be modeled with a fixed fault. Therefore, the stress state modeled in this study after injection of the cushion gas is closer to fault slip in the finite element model used than in a model where slip is allowed. Please note that even a finite element model with a sliding fault cannot reproduce the dynamic effects of seismic fault slip and the related relaxation, and therefore is also not able to precisely predict the stress state after seismic slip.

Since the objective of this study is to rank the different production and injection scenarios on the probability of fault slip, and not to predict the exact amount (or timing) of fault slip, it was decided that the advantage of a fixed central fault outweighs the disadvantages. The result of this decision is that since there is no stress relaxation after seismic slip, the calculated stresses and the related fault slip probability are a worst case scenario.

2.3 Initial stress state: 1D Geomechanical modeling

Fundamental for a geomechanical model (1D or 3D) is using the correct initial stress state. Input can be derived from local offset wells. The wells typically hold a multitude of partly high-resolution data sets including wire-line logs, well tests and in some cases rock strength measurements from core plugs. Combined with drilling experience, this set of related data allows constructing a detailed picture of the geomechanical conditions of the subsurface along the well trajectory at the moment the well was drilled.

The principal constituents of a 1D geomechanical model are the three in-situ principal stresses which are typically vertical stress (S_v), maximum horizontal stress (S_{Hmax}) and minimum horizontal stress (S_{Hmin}) along with their orientations. Furthermore, the pore pressure and the rock mechanical parameters (such as strength, internal friction and elastic moduli) are part of the geomechanical model which is constructed not only at a single point, but along the entire well trajectory as a function of depth. The parameters of the 1D geomechanical model are derived from a multitude of data depending on the availability of well logs and well tests. A more detailed description of these workflows is given in Brudy et al. (1997) and Zoback (2007).

The generated 1D geomechanical models are calibrated versus the drilling experience in the field. The final 3D geomechanical model is based on the 1D models and used as the initial stress state for the Abaqus finite element model.

2.4 Mechanical Property and Pore Pressure Population

The “water tight” structural model enables different material properties to be assigned to every formation in the model. The material properties used in the finite element model are based on the elastic properties calculated from the logging data in the 1D geomechanical models. All layers have poro-elastic properties except the Zechstein salt layer, which has visco-elastic properties.

The pore pressures in the model outside the reservoir layer are based on the pore pressure profiles generated in the 1D geomechanical models (mostly hydrostatic).

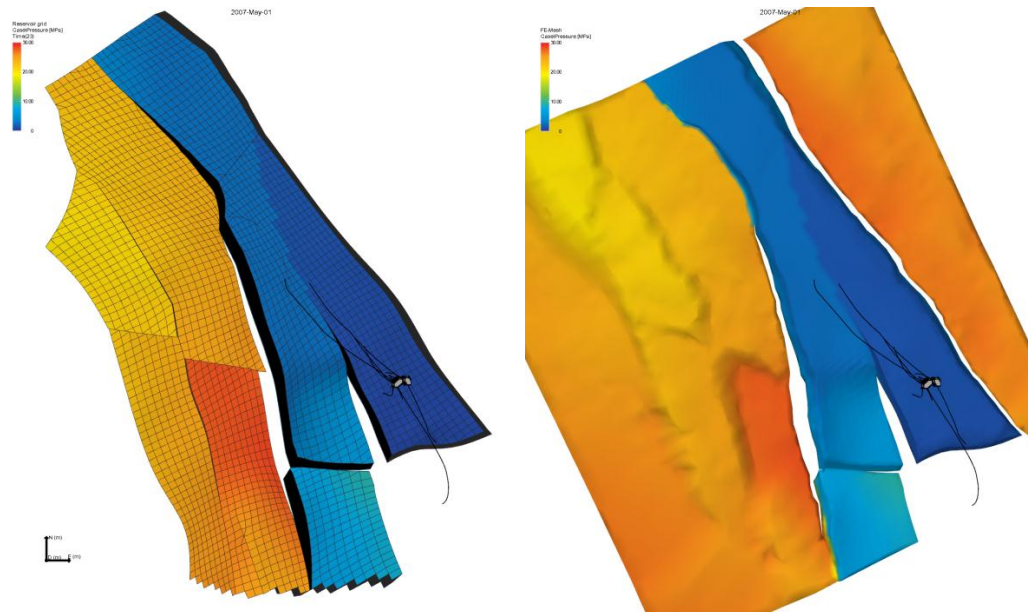


Figure 4. Mapping pore pressure magnitudes from the reservoir model (left) to the finite element mesh (right).

In the reservoir layer, the pore pressures are based on the pressures over time calculated for the reservoir model. The coupling between the reservoir model and the finite element model is done by mapping the pore pressures calculated by the reservoir simulation onto the nodes in the finite element model. The mapping reproduces the exact same pressure gradients in the finite element mesh as found in the reservoir model due to the exact geometric match of both, combined with the fine mesh in areas of interest (Figure 4).

Initially, three pore pressure scenarios for the underground gas storage are calculated with the reservoir model: a base case scenario and two extreme scenarios; one scenario with low production and injection rates and one scenario with very (unrealistic) high injection and production rates. All scenarios have the same minimum (7.7 MPa) and maximum average reservoir pressure (13.3 MPa). Based on the results and understanding of these scenarios, a fourth scenario is modeled which targets the most optimal operating conditions for the underground gas storage. The inputs of this scenario are listed in the discussion.

2.5 Finite element calculations

The stress changes caused by the changes in pore pressure over time are quantified in the finite element calculation. The finite element analyses are performed using the implicit iterative solver of Abaqus/Standard. The starting point for the simulations is the initial (1D) stress state. Abaqus is not offering an easy method for defining the initial stress state, with principal horizontal stresses not aligned with East-West or North-South. To solve this problem a two tiered approach is used as described in van der Zee et al. (2011).

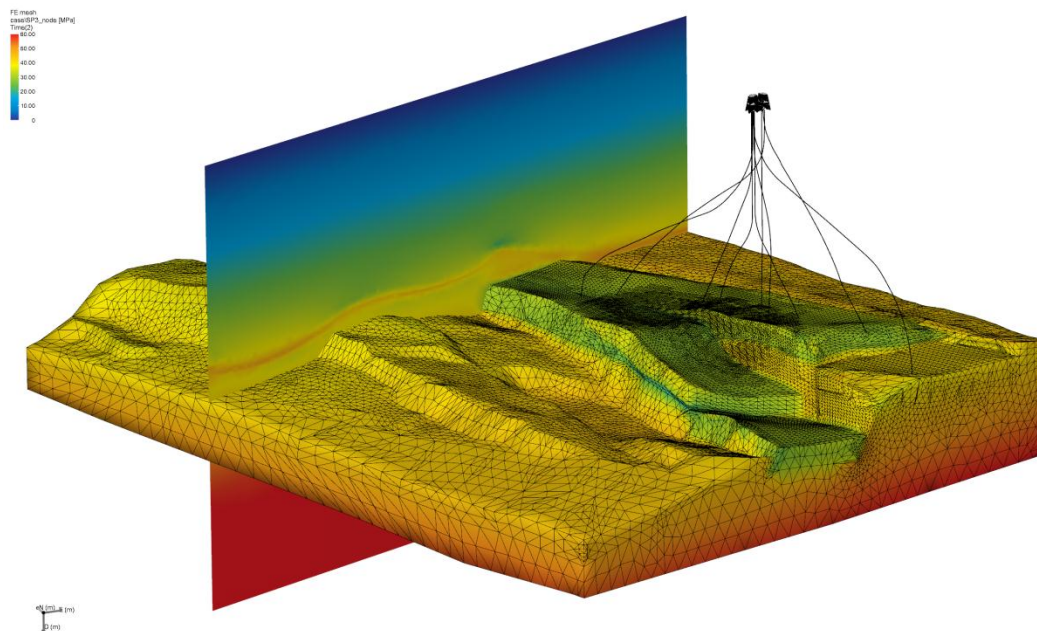


Figure 5. Example of results of the 3D finite element model. This figure shows the total minimum stress after the injection of cushion gas. The layer with high minimum stresses in the cross-section is the salt layer which has stresses near the overburden stress.

The finite element model starts with the initial stress state as described above. The pore pressures from the reservoir model, which are mapped on the nodes of the finite element model, are used as new and changing boundary conditions. This change in pore pressures results in changes in stresses over time in the model. To calibrate the model, the stresses are compared with borehole stress measurements such as Minifrac performed in the depleted reservoir.

The 3D finite element mesh consists of 262,868 2nd order tetrahedrons (C3D10M[P]) and 353,703 nodes. All elements have a pore pressure degree of freedom except the salt layer in the Zechstein formation. This results in a numerical problem with 2,429,193 degrees of freedom. The entire cycle from depletion, injection to UGS operation is modeled in at least 43 steps, with the highest time resolution on the last UGS cycle. An example of the finite mesh model is shown in Figure 5.

2.6 Fault stability calculations

After calculating the stress evolution during the depletion of the field, the injection of cushion and work gas and the underground gas storage (UGS) operation we can move to the next step in the work flow which is the fault slip assessment. In the 3D finite element calculation, the entire field is modeled as a continuum without any moving faults. The stresses on the fault surfaces are followed through all time steps in the model. For each time step the fault slip risk is calculated on every fault patch. Because of the pore pressure changes, and the related changes in horizontal

stresses, parts of the fault can become critically stressed. Under such conditions the fault may start to slip, which can be associated with seismicity.

The fault stability analysis is performed in respect to the subsurface stress conditions. The effective stresses are analyzed using Terzaghi's principle, which points to the importance of the pore pressure. For every element or triangle of the fault plane interpretation, the effective normal stress and shear stress on that plane are calculated. This is graphically illustrated for 2D in Figure 6. Using a Mohr Coulomb failure criterion for the fault with the cohesion set to zero and the friction coefficient set to 0.6, the calculated stress state of the individual fault element can be compared with the critical stress state defined by the failure envelope.

2.6.1 Tau ratio

A measure of the fault slip potential is calculating a relative property related to the shear stresses. For the Tau ratio, the observed shear stress τ is divided by the critical shear stress $\tau_{\max}$. If $\tau_{\text{ratio}} \ll 1$ then the fault is considered stable. If τ_{ratio} is close to 1.0 then a critical state is reached (Figure 6). The Tau ratio is commonly used to see the critical state potential of a fault surface as a whole. The fault plane figures with contoured values Tau ratio can be used to assess the risk of fault slip for that fault. If all other boundary conditions are the same, then a fault with higher Tau ratios or a larger patch size with high tau ratios has a higher risk for fault slip. If slip occurs, then the case with high value or large patch size is likely to slip over a larger distance. However, comparing two cases with different boundary conditions (like comparing the depletion of the field with UGS operation) can be misleading because physical effects such as (but not limited to) strain rate weakening are not taken into account in the presented model. The possibility that slip processes at two different time steps are different is too large to allow the comparison of patch size to be used to assess the magnitude of slip.

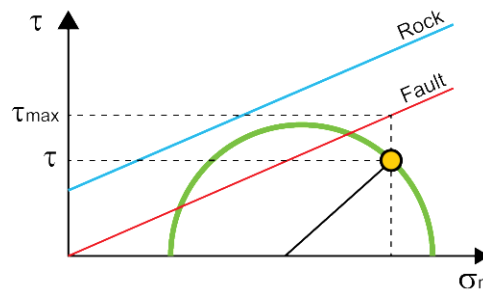


Figure 6. Tau ratio describes the fault slip potential by taking the ratio between the observed or calculated shear stress τ and the critical shear stress $\tau_{\max}$.

2.6.2 Tau Ratio Plots

The most critical part of the fault was determined using the analyses. A node is identified at which the principal stresses are extracted for the most important time steps in the analyses. These stresses are plotted as Tau ratio versus reservoir pressure. For the Tau ratio calculations, a constant

sliding friction coefficient (ϕ) of 0.6 is used. The value of 0.6 is an estimation based on Byerlee (1978).

The analysis shows the stability of an “optimally” orientated fault patch (with optimal it is meant a patch that is most favorably oriented for slip). The orientation of the central fault with respect to the regional stress direction is such that the azimuth of S_{Hmax} is very close to the fault strike. Therefore, most of the variation in angle between the principal stress and fault are controlled by the fault dip. The fault dip in the structural model is determined by the seismic analysis. This analysis probably ‘smoothens’ the fault because it cannot determine small variations in orientation which are below the seismic resolution.

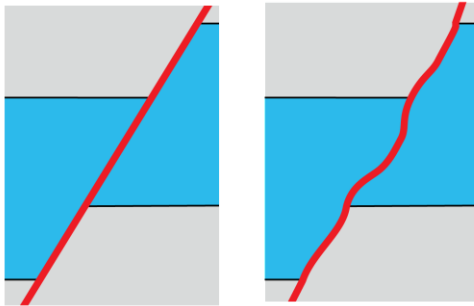


Figure 7. Conceptual drawing to visualize the difference in orientation of fault patches between the low resolution interpretation (left) and the real fault orientation (right).

Figure 7 illustrates the effect of a low resolution interpretation not being able to follow all small variations in orientation. The fault roughness occurs on many orders of scales both along dip and along strike of the fault (e.g. van der Zee & Urai, 2005). It is believed that the combination of the fault orientation and stress orientation in this project allows using the Mohr analyses to evaluate the probability on fault slip because the probability that a fault patch is optimally oriented is very high.

The assumption made above (that there will be a fault patch optimal oriented for slip) means that it can be assumed that in all Tau ratio plots in this paper **the worst case scenario** is analyzed. This assumption is further discussed in paragraph 4 (discussion) of this paper.

As described in paragraph 2.2 (Generating 3D Finite Element Mesh) it is unknown which pore pressure is present in the fault at the slip surface. Therefore, in the rest of the paper the fault slip risk is evaluated using pore pressures from the east block (block I) and the west block (II) separately.

3. Results

The modeling results show that the area with the highest fault slip risk is located where the top of the reservoir on the west side of the fault crosses the base of the reservoir on the east side of the fault (Figure 8). This is exactly the area where the post-processing node is located which will be used in the paragraphs below.

3.1 Depletion and cushion gas injection

The stress situation before depletion of the field is plotted as the Tau ratio versus the reservoir pressure in Figure 9. Before the reservoir depletion, (average reservoir pressure = 23 MPa) the stress state is far below the critical line (indicated by Tau ratio = 1), meaning the fault is considered stable in the initial stress field. During the depletion of the field the stresses at the fault change. The red lines in these plots are the stress state assuming that the pore pressure of the west block is present in the fault and the green lines are assuming the pore pressure of the east block in the fault. The red dots indicate the pairs of earthquakes. The results in Figure 9 show that the stress state at the most critical point when the first earthquakes occurred was such that a fault patch optimally oriented for slip is unstable if the average pore pressure or the pore pressure from the west block is present in the fault.

The fault stability analyses during the injection of the cushion gas and work volume for the underground gas storage show that with the injection of the cushion and work gas the fault becomes more stable. Figure 9 shows that the stress state at the highest reservoir pressure after injection of the cushion gas and work volume is significantly below the failure line, which means that the fault patch is stable at these conditions. The stress paths are different during the injection phase than during the production phase due to the differences in pore pressure distribution left and right of the fault.

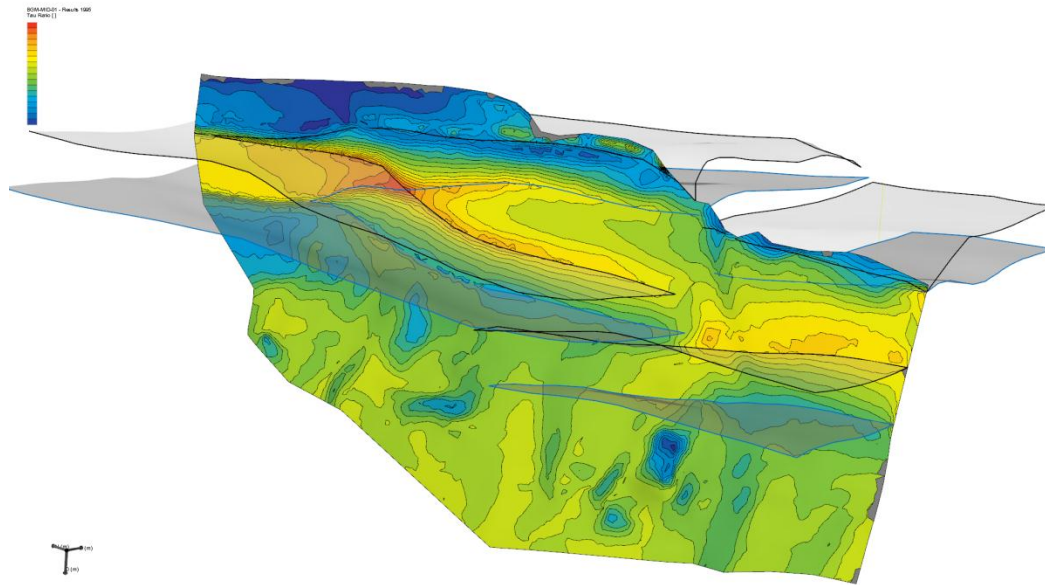


Figure 8. Central fault in 3D from the south-west. The property displayed is Tau ratio. The top and base of the reservoir are transparent in the figure for better visualization of the area of interest.

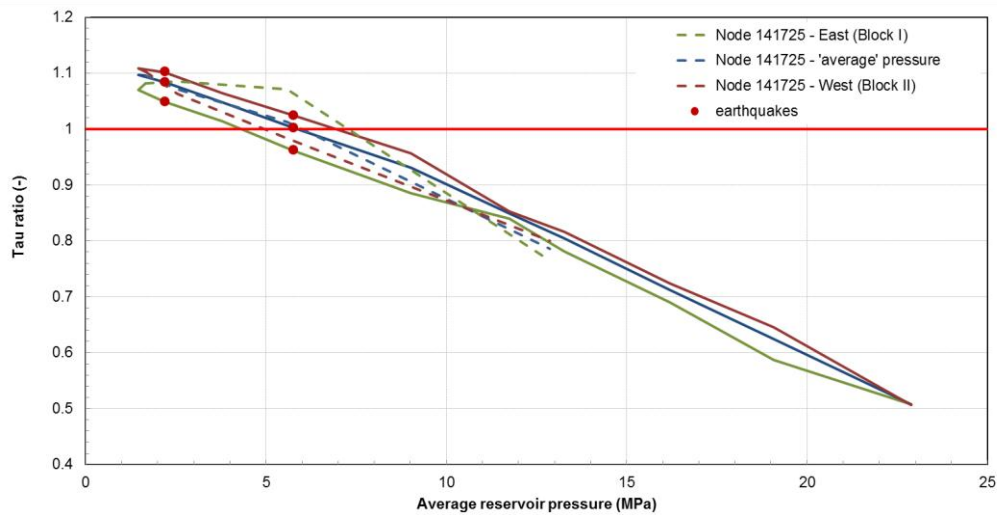


Figure 9. Tau ratio versus reservoir pressure for the depletion phase (solid line) and the cushion gas injection phase (dashed line). Red dots indicate the stress state at the time of the earthquakes which occurred during the depletion of the field. Data plotted from the most critical node. Please note that Tau ratios > 1 are possible in the finite element model used in this study because fault is not allowed to slip, which would limit Tau ratio to the theoretical value of 1.0.

3.2 Base case: moderate gas injection and production rates

The base case scenario has moderate gas injection and production rates. It should be noted that the reservoir model cases are all unmanaged. Because of the unmanaged nature of the model, the pore pressure increase and decrease in both blocks are not synchronized. At the most critical node, the east block reaches its lowest pore pressure before the west block.

The reservoir model shows that the pore pressure in the west block is higher. Therefore, if this pore pressure is present at the fault surface, then the corresponding effective stress is lower and the fault is closer to being critically stressed. Figure 10 shows that even assuming the worst case scenario, (no stress relaxation during the earthquakes, the highest pore pressure in the fault, and a fault patch orientation most likely to slip) the fault at this most critical location is predicted to be close to failure but stable at the lowest pore pressure of the UGS cycle.

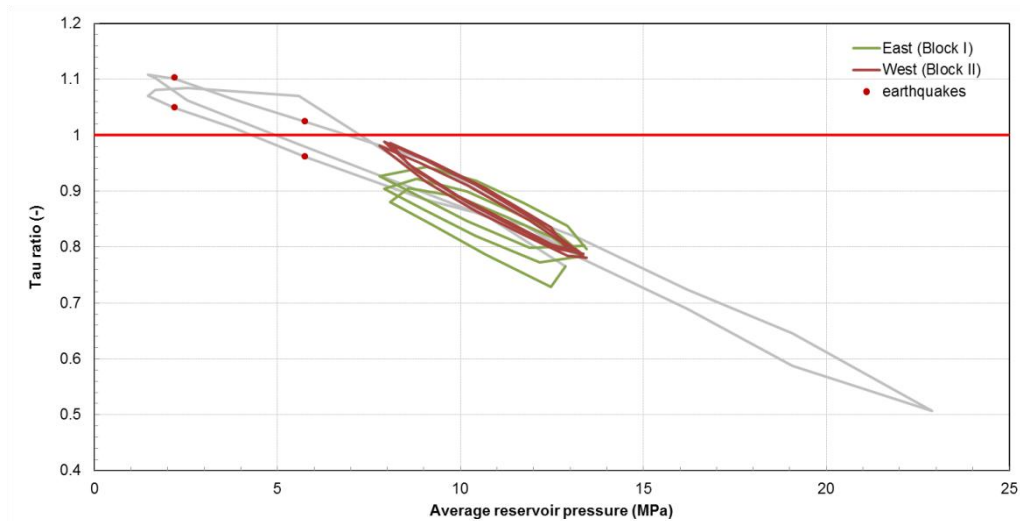


Figure 10. Tau ratio versus reservoir pressure evolution for the most critical node in the base case. The grey curve is the path during depletion and injection of cushion gas and work volume. The red and green curves are the stress paths during the UGS cycles. The horizontal red line is the Tau ratio =1 line.

3.3 Slow injection and production rates

The injection rates used in this case are the lowest possible within a one-year cycle, between 7.7 MPa and 13.3 MPa average reservoir pressure. This scenario is used to investigate the effect of low injection and production rates on the stability of the central fault. The reservoir model shows that at the most critical point the pore pressure increase and decrease on both sides of the fault are synchronized, and the across fault pressure difference is small.

Figure 11 shows that despite assuming the worst case scenario (no stress relaxation during the earthquakes, the highest pore pressure in the fault, and a fault patch orientation most likely to slip) the fault at the most critical location is predicted to remain stable. The different cycles all have similar results because the pore pressure changes from cycle to cycle at the critical node are relatively small.

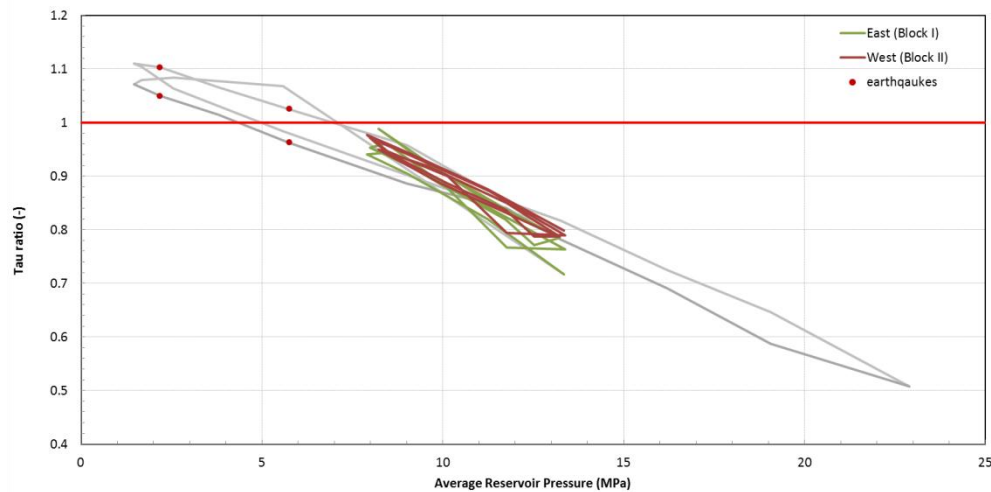


Figure 11. Tau ratio versus reservoir pressure evolution at the most critical node in low-rate case. The grey curve is the path during depletion and injection of cushion gas and work volume. The red and green curves are the stress paths during the UGS cycles. The horizontal red line is the Tau ratio ≈ 1.0 line.

3.4 Extreme high injection and production rates

The injection rates used in this scenario are unrealistically high and are not possible with the planned facilities. This scenario is run for illustration purposes only to investigate the effect of very high production and injection rates.

The reservoir model results show that at the most critical node, the pore pressure increase and decrease are not synchronized. At this node, the east block reaches its lowest pore pressure before the west block. The phase shift is quite constant through all cycles, with the highest pore pressure in the west block. The pore pressure difference between the east and west block across the fault at this point does not get much smaller during the cycles calculated in this scenario.

Because the pore pressure in the west block is higher, this means that if this pore pressure is present at the fault surface, then the effective stress is lower; and therefore that the fault is becoming close to critically stressed. Figure 12 shows that if the worst case scenario is assumed (no stress relaxation during the earthquakes, the highest pore pressure in the fault, and a fault patch orientation most likely to slip), then the fault at the most critical location and orientation is predicted to be critically stressed at the lowest pore pressure in the UGS cycle.

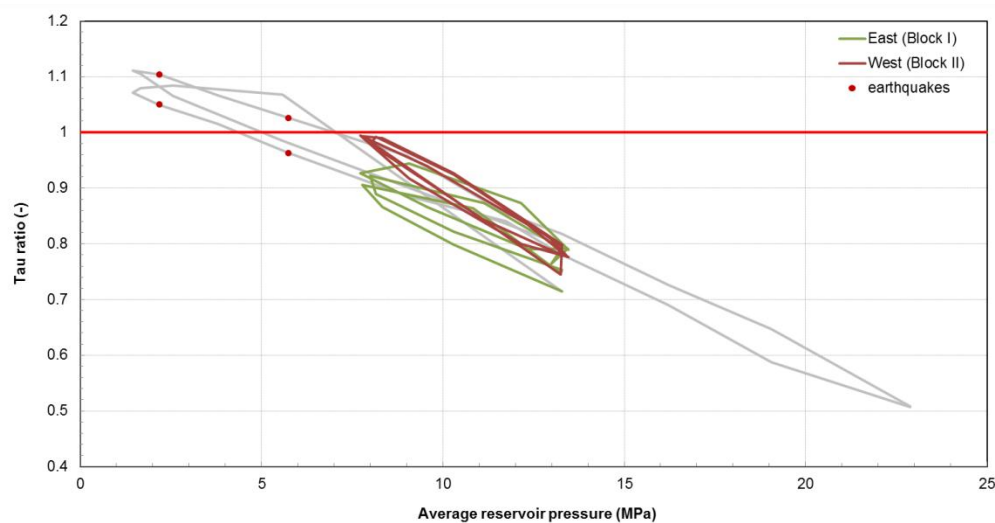


Figure 12. Tau ratio versus reservoir pressure evolution at the most critical node for the extreme rate case. The grey curve is the path during depletion and injection of cushion gas and work volume. The red and green curves are the stress paths during the UGS cycles.

4. Discussion

The main objective of this study is reviewing the effect of different injection and production rates on the central fault stability and the associated seismic response of the reservoir. The results of the modeled scenarios show that there is a relationship between the maximum production and injection rates and the pore pressure distribution on both sides of the fault. The lowest production rate scenario results in a lower pressure difference across the fault. With low production and injection rates there is no phase shift in pressure at one single point. On the other hand, the high production and injection rate scenario shows a large pressure difference and a large phase shift, which doesn't dissipate over the cycles simulated in the study. This pressure difference across the fault at the most critical location can lead to a nearly critically stressed fault if the pressure on one side is low enough to critically reduce the total horizontal stress, and at the same time, the pore pressure on the other side is relatively high (compared to the low total horizontal stress).

The lowest fault slip risk observed in low rate scenario suggests that lower rates lead to safer operations. However, it is assumed that safer operations can also be achieved by combining higher injection and production rates with balanced reservoir management, which avoids pressure differences between the blocks. To prove this assumption, a new reservoir model was developed with moderate injection and production rates but in contrast to the base case, this scenario contained a control to minimize the across fault pressure difference at the most critical point.

Figure 13 presents the results of this analysis. The pore pressures at the most critical point have no phase shift, and the difference in across fault pore pressure at this node is very small (<0.5 MPa) at the lowest reservoir pressure for each cycle. This results in a model where even in the worst case scenario (fault patch optimal oriented for slip, and highest pore pressure at the fault plane) all cycles are stable.

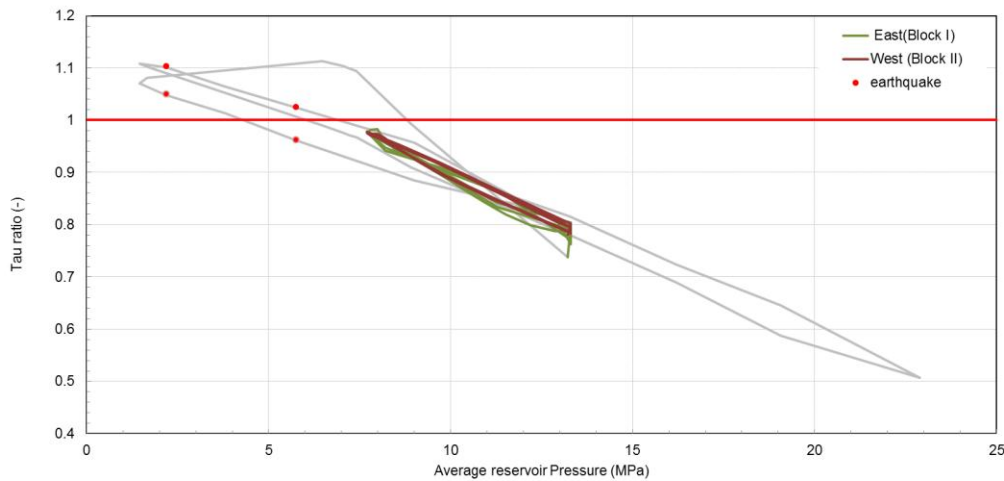


Figure 13: Tau ratio versus reservoir pressure evolution for the most critical node in a balanced reservoir scenario with moderate injection and production rates. The grey curve is the path during depletion and injection of cushion gas and work volume. The red and green curves are the stress paths during the UGS cycles.

4.1 Sensitivity analysis

All analyses are assumed to be worst case scenarios since it is assumed that the fault patch at the most critical point is oriented optimal for slip. However, to validate the assumption, a Monte Carlo simulation of many of the input parameters to the fault slip analysis is performed.

In the Monte Carlo method, calculations are run a large number of times. In each realization, the input parameters are altered by a random offset from a base case. The parameters are specified by giving a mean value and standard deviation. Each population is calculated by using the Box-Müller algorithm that produces a Gaussian distribution.

After running a few thousand realizations, the results are analyzed for a P10, P50 and P90 answer. P50 corresponds to the most common or most likely outcome, whereas P10 and P90 mark the lower and upper 10% of the analysis. The population between P10 and P90 consequently holds 80% of the scenarios. In this study, the last cycle of the last scenario is used for the most critical node. The Monte Carlo simulation was chosen because there is only a single location with a high number of realizations (100,000 per time step).

Table 1 presents the input values and their standard deviations.

The results of the Monte Carlo simulation are plotted together with the results of the last UGS cycle of the managed reservoir model in Figure 14. This figure shows that the presented results are very close to the P90 results of the Monte Carlo simulation. This means that close to 90% of the simulations run in the Monte Carlo simulations result in better fault stability.

As a result, the presented results are conservative because many other combinations of input variables result in higher fault stability.

Table 1. Input parameters for the Monte Carlo simulation.

Parameter	Value	Standard deviation
Friction Coefficient	0.6	+/- 0.05
Fault Dip	65	+/- 7.5°
Fault Azimuth	225	+/- 10°
Pore Pressure	Pp (t)	+/- 0.25 MPa

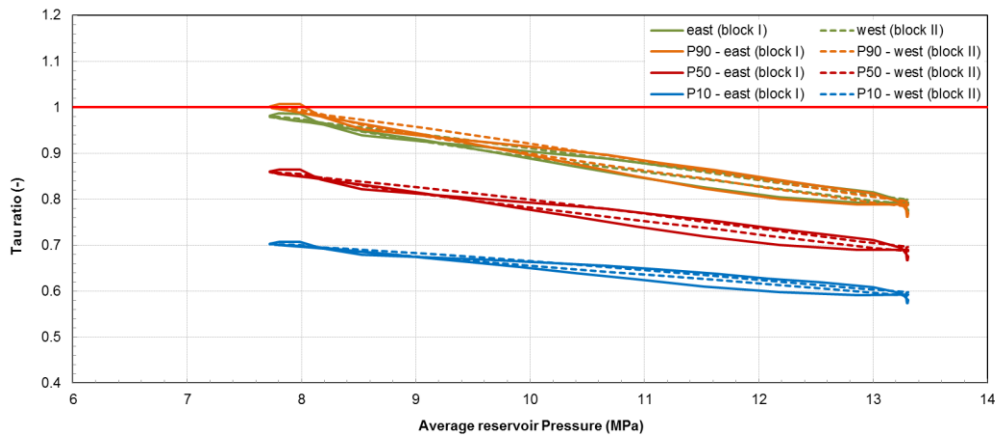


Figure 14: Tau ratio versus average reservoir pressure for the most critical node. The green line is the result of the last scenario. The orange line is the P90 result, the red line is the P50 result and the blue line is the P10 result.

5. Conclusion

- The results of the 3D dynamic geomechanical model for the depletion phase are in agreement with the observed locations and timing of the induced earthquakes and confirm the validity of the models (successful history match).
- Increasing the reservoir pressure increases the stability of the central fault, whereas decreasing the reservoir pressure reduces the stability of the central fault, however, not necessarily to the critical point.
- The only effect gas injection and production rates have on the fault stability are caused by pressure gradients in the model. For unmanaged reservoir models, the scenario with low injection and production rate is the most stable. However, this study shows that with a managed reservoir the same stability can be achieved as the low rate scenario.
- Monte Carlo simulation on the fault stability analyses shows that the results in this paper can be considered conservative because the results are close to the P90 values of the Monte Carlo simulation.
- The multi-disciplinary (geomechanics and reservoir engineering) approach used in this study resulted in an UGS operational plan not only controlled by reservoir engineering, but strongly guided by the geomechanical finite element modeling.

6. Acknowledgements

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