STRESS DISTRIBUTION MODEL IN WATER INJECTION WELL

by

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Dissertation submitted in partial fulfillment of

the requirement for the

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CERTIFICATION OF APPROVAL

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AHMAD FADZLI BIN MOHAMAD YUSOF

A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the
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Approved by,

____
(Dr Sonny Irawan)

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May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work in my own except as specified in the references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

(AHMAD FADZLI BIN MOHAMAD YUSOF)

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ABSTRACT

Geomechanics study is often overlooked in oil and gas industry whether during drilling, completion or production phase in Malaysia. Generally, geomechanics is the study of behavior of soil and rocks. These two principles are connected each other and can be further explained in stress and strain distribution concept. This project covers the study of rock mechanics by manipulating the vital parameters such as Poisson's ratio and Young's Modulus, effects of stress distribution around water injector well. The study is conduct by two approaches; one-dimensional approach which cover the changes around the wellbore and three-dimensional approach, which cover the reservoir simulation. In one- dimensional approach, the parameters studied are Young's modulus and Poisson's ratio while in three-dimensional approach, the parameter of interests are well injector pressure, plastic shear strain and plastic displacement. The results from the simulations is as the water is injected, the stress decrease and stain increased. On the other hand, in reservoir approach, after water is injected, the well injector pressure decreased, plastic shear strain increased and plastic displacement decreased. A positive stress means compaction of rock which results in negative strain while a negative stress means expansion of rock and results in positive strain. The water injector pressure is decreased after water is injected is due to the pressure decline is much greater as compared to the one with injection. An increased in plastic shear strain means pore spaces expand or increase because of the more pressure applied after water injection. The negative value in z-plastic displacement means compaction drive took placed after water injection which is good for the reservoir.

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All contributions are much appreciated.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Plate tectonics is a scientific theory that describes large-scale motions of the Earth's lithosphere. A model was built on the concepts of continental drift, developed during the first few decades on the 20th century. Geoscientific community accepted the theory after the concepts of seafloor spreading was developed in late 1950s and early 1960s.The analogy is the same as the application of Newtonian mechanics, whether it is statics or dynamics. Rock mechanics is the application of Newtonian mechanics to the study of rocks in the ground. In fact, it is concerned with how the rocks behave in response to disturbances and alteration brought by excavation, changes in stress, fluid flow, temperature changes, erosion, burial and other phenomena. Geomechanics involves the geologic study of the behavior of soil and rock which related to rock mechanics and geotechnics. Geomechanics studies have growing its importance in oil and gas industries because of its effect on reservoir performance. To relate it with oil and gas industry, geomechanics is used to predict important parameters such as in-situ rock stresses, modulus of elasticity, formation fracture pressure and Poisson's ratio. Reservoir parameters that include: formation porosity, permeability and bottom-hole pressure can be derived from geomechanical evaluation. A common example of geomechanics effects on reservoir are reservoir compaction and surface subsidence. There are more operational problems related to subsidence such as risk of flooding in land or platforms.

If a force is distributed over a surface, the magnitude of the force with respect to the area on which it acts is known as stress. Stress that act on a body which has some rigidity may have different magnitude in different direction of stresses. The stresses in different direction ac independently and cannot be added to obtain a resultant. In other hand, if the material has no rigidity, the stresses in all directions are the same. This particular state of stress is called pressure, with negative pressure being a vacuum. If a fluid is compressed it reacts by exerting an equal and opposite pressure outwards. Stresses and pressures within the same material can increase with depth, which both of the magnitude can be normalized with respect to depth in order to obtain pressure gradient or stress gradient .This concept can be seen in in-situ reservoir is original location or position of reservoir that has not been disturbed by faults or landslides. When drilling process take place, the in situ reservoir which have reached the equilibrium over hundreds of years, are altered in terms of stress, which lead to many more changes in reservoir parameters. Reactions of formations to the changes of stress have attracts many exploration and production (E&P) companies to focus on the matter.

Enhanced oil recovery (EOR) is a generic term for techniques for increasing the amount of crude oil that can be extracted from an oil field. There currently are several different methods of EOR including steam floods, water injection, hydraulic fracturing, polymer flooding, hydrocarbon gas and CO2 flooding and many more. Water injection is one of the EOR methods to increase pressure and stimulate production. Water injection wells can be found both on and offshore. The concept of water injection well is water is injected from the well to support pressure of reservoir which is also known as voidage replacement and to sweep oil from the reservoir, and push it towards production well. Normally a reservoir can only extract 30% of the oil from natural drive, but water injection increases the recovery factor and maintains production rate of a reservoir over a longer period. Sources of injected water are commonly produced water from the reservoir itself because it can reduce the potential of causing formation damage due to incompatible fluids. Other than that, most convenient source for offshore production facilities is seawater but filtering, de-oxygenation and biociding is generally required to avoid corrosion. Other alternatives than seawater are aquifer water from water-bearing formations other than the oil reservoir and river water which also required filtration and biociding before injection.

Developing a geomechanical model for a reservoir involves huge amount of money, risks and uncertainties. There are few considerations are taken into account when developing model for EOR injection wells. In the past, most drilling and production departments were not particularly attuned to formation stresses and geomechanics; many reservoirs were deemed technically straight-forward and had undergone only limited depletion. Declining in resource volumes and favorable oil prices are prompting operators to drill deeper, more intricate well trajectories, at the same time that new technologies are extending the lives of mature fields. Failure to appreciate the importance of geomechanics may have severe consequences such as excessive mud loss, wellbore instability casing compression or shearing and many more. (Cook, et al., 2007)

1.2 PROBLEM STATEMENT

Geomechanical studies have been neglected nowadays during injection scheme. During injection phase for EOR, wellbore must be in stable condition to ensure a safe operation. Otherwise, problems such as wellbore instability, solid productions, casing shear and reservoir compaction may arise. Geomechanical stress distribution model is wanted in every field development and should be maintained for life-time of the field in order to contribute safe and optimum injection in depleting and complex reservoir. During the injection process, the injected fluid will alter the original in situ reservoir condition or the original condition at wellbore.

Some parameters that are affected by the injection are mechanical cohesion – stress and strain, and initial pressure at wellbore. Stress and strain are two important factors that need to be considered before planning a well. For instance, as reservoir depleted, horizontal and vertical stresses change in different ways and may cause well orientation. During water is injected into reservoir, the stress and strain around near wellbore also changes. It is significant to control the water injection rate to get ensure stable well condition. Other than that, it is important to predict the fracture geometry near the wellbore for future use such as analyzing hydraulic fracturing and optimum pumping rate.

Research about this project is significant as increasing demand of oil and gas in the world nowadays. With the knowledge of geomechanics, exploration and production companies will be able to identify risks mitigate and improve ultimate oil recovery. The risks at near well bore, inter-well bore and field-scale should be identified before further operation is continued.

1.3 OBJECTIVE OUTLINE AND SCOPE OF STUDY

The purpose of project can be summarized as follow;

- To develop stress distribution model around water injector well.
- To determine the well injector pressure, plastic shear strain and plastic displacement.

1.4 SCOPE OF STUDY

From the research, a model will be developed to study the relationship between mechanical response and injection rate and pressure. There are many types of EOR technique such as waterflooding, steam injection, water-alternating-gas injection, polymer flooding, CO_2 injection and many more. Each type of EOR approach has its own considerations and results. It is important to know the considerations for each type of EOR approach so that an expected result can be predicted. For the scope of the study, water injection is taken as main approach in this project.

As a petroleum engineer, the study of geomechanics is important because it contributes to better understanding of reservoir properties and how to mitigate the risks. The stresses and strains act near wellbore could pose risks such as casing damage, fracturing and wellbore instability. The risks can be reduced with the knowledge of geomechanics as these type of risks would cost problems in drilling, production and millions of dollar if is not taken seriously.

The objectives and completion of the project is feasible by the given time frame as the scope of study is narrow down to specific parameters. As geomechanics is a very broad subject, only few parameters will be simulated and investigated in this project. The time give to complete the research is approximately six months. With availability of software needed to run simulation, it eases the author to learn how to use the related software. The project will focus on the effects of water injection rate to production performance and simulate a geomechanical stress distribution model for the injection well. By developing the geomechanical stress distribution model, it helps to understand the behavior of a reservoir and test the theory learnt.

CHAPTER 2

LITERATURE REVIEW

2.1 ROCK MECHANCICS

Basic concept in rock mechanics are stress and strain. Normal stress act perpendicular to a face or plane while shear stress acts parallel to the plane or face. Both normal stresses and shear stresses are vital of importance in rock mechanics since the application of a normal stress across a plane results in generation of different shear stresses in other planes.

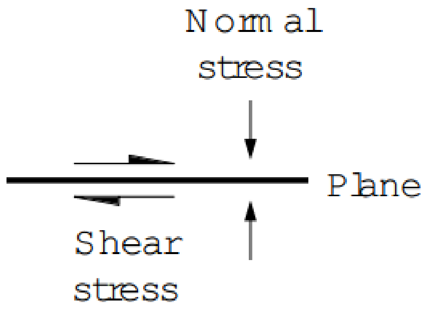


Figure 1: Normal and Shear Stress

Considering a 2-dimensional body subjected to a normal stress σ_1 in one axis and a normal stress σ_3 in the other axis, with these two applied stresses acting at right angles to one another. Although σ_1 and σ_3 are the only stresses applied to the outside body, other stresses will be induced throughout the body. Considering an imaginary plane 'a' inclined at an angle â with respect to the body, this plane will be subjected to an induced normal stress σ_a which acts to push the surfaces of the plane together and an induced shear stress τ_a which tends to cause the surfaces of the plane to slide relative to one another.

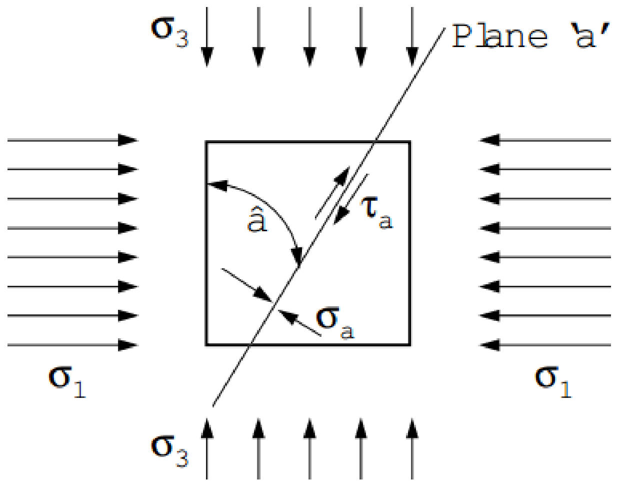


Figure 2: Induced normal stress and induced shear stress

The relation between the applied normal stresses and the induced normal and shear stresses can most easily illustrated for this 2-dimensional situation using Mohr's circle, in which normal stresses appear on the horizontal axis and shear stresses correspond to the vertical axis. An angle â appears as an angle 2â on Mohr's circle and planes at different angles â measured with respect to the plane on which σ_1 acts will be subjected to different normal stresses σ_n in the range σ_3 to σ_1. Different shear stresses τ in the range zero to $(\sigma_1 - \sigma_3)/2$ with the maximum τ acting at 45° to σ_1 to σ_3.

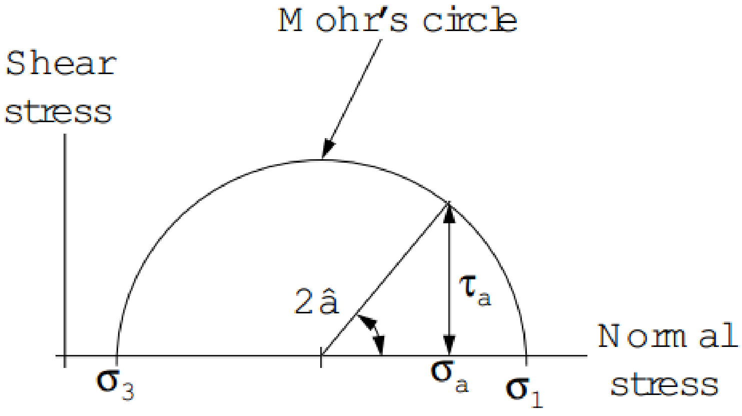


Figure 3: Mohr's circle

In this case, since σ_1 is the only stress acting on its plane and since σ_3 is the only stress acting on its plane, there are no shear stresses acting on these planes. These stresses are known as principal stresses. Other than that, σ_1 has the greatest magnitude if any of the normal stresses action on the body it is known as maximum principal stress while σ_3 has least value known as minor principal stress. For 3-dimensional situation, there will be a third principal stress known as the intermediate principal stress σ_2. In all cases, whether it is 2-dimensional or 3-dimensional, the principal stresses always act perpendicular to one another and there are no stresses τ associated with the planes on which the principal stresses act.

When a body is subjected to any stress it will deform and undergo deformation. However, it is often to quantify the deformation in terms of the original dimensions of the body. For instance, a block of rock might be compresses by 2''; the relative effect would be different if the block was originally a 10'' cube as against a 100'' cube. Therefore, deformation is often normalized with respect to some unit length or original dimension of the body and the normalized quantity is termed as strain. For example, a 1000'' column which is compressed axially and undergoes 2'' of deformation is said to have undergone ${}^{2}/_{1000}$ of a unit strain, or 2 mill strains or 0.2% strain. If rock undergoes deformation and strain which are recoverable, it is known as elastic deformation or elastic strain. Linear-elastic behavior simply means that there is a linear relation between an applied stress and the elastic strain which result from the application of this stress. If however, the deformation or strains are permanent or unable to recover, it is termed plastic deformation or plastic strains.

The stiffness of the rock is its ability to resist being deformed and straned due to the application of stress. The compressibility of a rock is the inverse of its stiffness. If the deformation being considered is elastic, then the stiffness of a rock with respect to a particular stress is termed its modulus, the magnitude of stress needed to cause unit elastic strain or also known as Young's modulus. Young's modulus is the ratio of $\frac{normal\ stress}{strain\ in\ the\ same\ axis}$.

When rocks and other materials are compressed in one direction they respond by expanding outwards in the other perpendicular directions. A simple analogy can be imagined by squeeze a soft rubber between ones fingers and see it bulge outwards in the other directions. This effect is known as Poisson effect and Poisson’s ratio is the ratio of$\frac{lateral\ strain}{axial\ strain}$. In terms of elements of rock in the ground, the Poisson effect plays an important role in generating stresses and providing support to other adjacent element of rock.

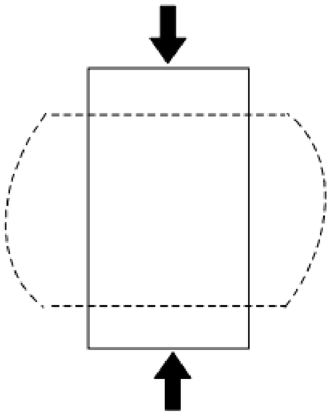


Figure 4: Poisson effect

Considering one element of rock within a larger mass, and if the whole rock mass is subjected to a given stress in one direction, the element must be prevented from expanding laterally since its neighboring elements are attempting to do the same but in opposite directions. Unless a particular element of rock is bounded by a free-face which is able to move for instance the surface of a borehole, lateral stresses and hence lateral support must be generated within the rock due to Poisson effect.

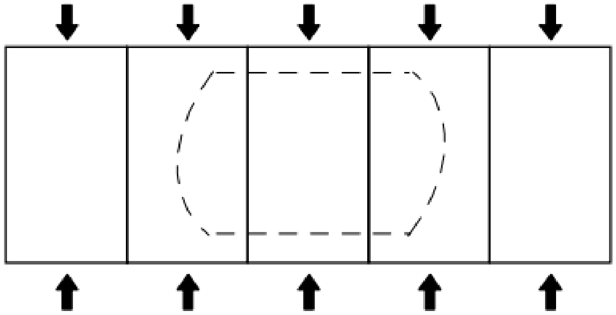


Figure 5: Poisson effect in one element within a larger mass

2.2 STRESSES IN UNDISTURBED GROUND

Rock buried deep in the ground is subjected to high stresses and usually differ in different directions since they originate from many different sources. For example, vertical stress at a particular depth will be due to the weight of overlying formation. This is also known as overburden stress. The effect of the overburden stress will tend to spread or expand the underlying rocks in the horizontal lateral direction due to Poisson effect. However, tendency for lateral movement will be restrained by the presence of adjacent material. Therefore horizontal lateral stresses which result in confining the rock. Regional tectonic stresses might cause earthquakes or mounting-building contribute further to these horizontal stresses.

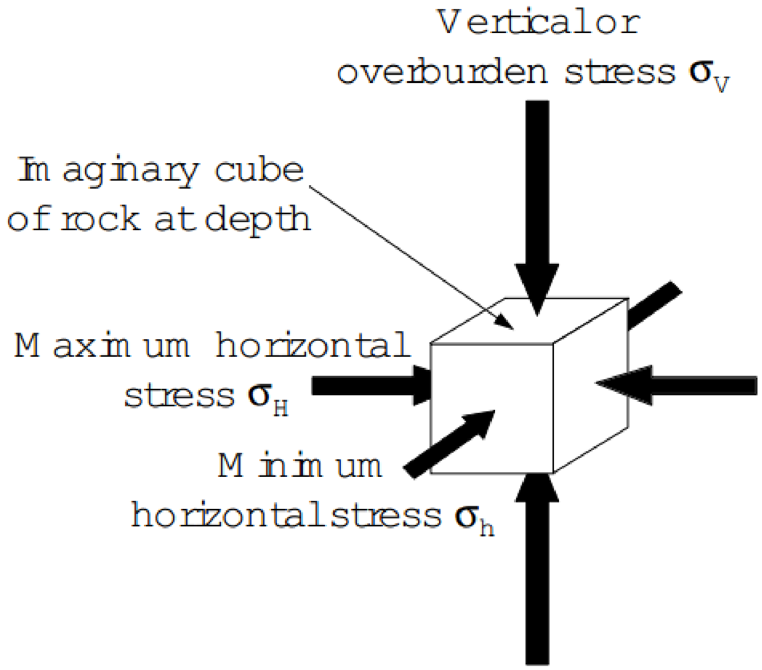


Figure 6 : Overburden, maximum horizontal and minimum horizontal stress

In the undisturbed state before any engineering activity, the states of stress in the rock will generally be compressive and can be simplified and approximated to a vertical or overburden stress, σ_v , a maximum horizontal stress, σ_H , and a minimum horizontal stress, σ_h. Most importantly, it should be remembered that stresses acting in different directions act independently as they are tensor quantities and as such they cannot be added together to obtain a single equivalent value.

2.3 EFFECTIVE STRESSES AND ROCK FAILURE

The application of boundary stresses on a rock will cause it to undergo deformation. If these changes in the stresses are small, the deformation may be recoverable and no permanent strain will occur. This is known as elastic deformation. Elastic deformation in a rock occurs mainly as a consequence of elastic strains and deformations within its constituent grains and cementing materials. If the boundary stresses are excessive, the rock may undergo some degree of failure and permanent deformation. This is known as plastic deformation and it occurs mainly as a consequence of crushing and fracturing at grain boundaries and contacts, and in the cementing materials. The resulting deformations and strains are generally greater than those associated with recoverable elastic deformation.

The effect of the boundary stresses are diminished by the presence of pore pressure. This is due to the pore pressure acts in all directions from within the rock and helps to support some parts of the applied boundary stresses which would otherwise be transmitted through the rock via grain-contacts and cementing. It is those components of the boundary stresses which are not relieved by the pore pressure that are responsible for the deformation and failure of the rock. These components of stress are known as effective stresses or net stresses.

$$Effective\ stress\ \sigma' = Boundary\ stress\ (total\ stress)\ \sigma - pore\ pressure\ u$$

The term total stress mean the stress acting at the boundary of the element of rock as against that which would be transmitted through the grains of the rock.

If one or more of the total stresses becomes significantly large or if the pore pressure is such that the difference between the effective stresses in one direction is sufficiently greater than the effective stress acting at right angles to it, the material undergoes a different mode of failure termed shear failure. This occurs when the shear stress acting with respect to some imaginary plane in the material exceeds the shear strength of the material.

2.4 GEOMECHANICS CONSIDERATIONS IN WATER INJECTION WELL

The study is focusing on the geomechanical stress distribution model in EOR injection well. It is significant to develop stress distribution model to know optimum injection rate, stress and strain response, and plan trajectory of a well. For stress and strain part, the parameters that are needed are Young's Modulus, Poisson's ratio and Biot coefficient. As for the injection rate and pressure, Mohr's Coulomb theory is significant to have understanding about failure criteria correlation. The existing Gulfaks reservoir model was embedded with overburden, side-burden, under-burden and stiff plate so that we can simulate the actual reservoir condition. Horizontal length of the side-burden should be long enough so that the boundary effects can be evaded. Vertical length of the embedded model replicated the mechanical parameters of the reservoir. Aspect ratio of lateral length to vertical length is archived to ensure the original reservoir model will not bulk in the course of stress and strain simulation. The main parameters integrated during this research are as follow;

- Young's Modulus

  $E = \sigma/\varepsilon$ ……………………. (1)

  Where E = Young's modulus, σ = applied stress and ε = resultant strain.

  Young's Modulus is the ratio applied stress to resultant strain. This parameter can be consider as the stiffness of a material, where decreasing the ratio given will allow more deformation to be formed.

- Poisson's ratio

  $v = -\varepsilon\, transitional/\ \varepsilon\, longitudinal$ ………. (2)

  Where v = Poisson's ratio and ε = resultant strain.

  Poisson's ratio is the ratio of negative lateral strain (decrease in thickness) to the axial strain (longitudinal length). This parameter will effects on the strain applied as well as the displacement in any direction.

- Mohr’s Coulomb

  $F = P\sin\theta\ (J\cos\theta - \frac{\sin\theta sin\emptyset}{\sqrt{3}}) - c\cos\ \theta$ ……………….. (3)

  Where F = Mohr Coulumb potential function, P = mean stress and J = deviatoric stress

  Usually, Mohr’s Coulomb is used to define shear strength of soil and rocks at different effective stress.

2.5 GEOMECHANICAL STRESS DISTRIBUTION MODEL IN WATER INJECTION WELL

Water flooding is the most widely used around the world as the method to increase oil recovery. Parameter such as well placement, well type, and optimal rate selection is decisive to improve water flooding performance. An optimal rate selection is crucial as the rock near wellbore might fracture and damage the reservoir. Injection rate is related with stress distribution near wellbore or in the reservoir according to the Terzaghi Law (Terzaghi, 1943) (Teklu, Alameri, Graves, N, tutuncu, & Kazemi, 2012) that relates effective stress (σeff) with pore pressure, *p*.

$\sigma eff = \sigma - \alpha p$ ……………..(4)

Where, α is Biot’s coefficient and σ is stress.

Biot coefficient is also a strong function of stress changes (Mese and Tutuncu, 2000) and is calculated by

$\propto = 1 - \frac{K_b}{K_{grain}}$ ………………………. (5)

Where K_b and K_{grain} are bulk and grain modulus respectively.

The stress changes can be triggered by reservoir temperature cooling or pore pressure fluctuations, especially in water-alternating-gas (WAG) flooding (Rui, Xiang'an, Renbao, Pingxian, & Freeman, 2009). In addition, parameters such as well placement and well type are also important to improve water flooding performance other than mentioned before. Water flooding experiment performed by Muralidharan *et al.* (2005), both on fractured and un-fractured sandstone core at different stress condition (uniaxial, triaxial and hydrostatic stress), show that fluid flow from fracture dominates when the applied confining stress is small (Figure); on the other case, fluid flow from matrix may increase as applied stress increases (Figure). This could be due to conformance modification as water flows into the matrix with increasing confining stress. Therefore, recovery may be improved by operating an optimal stress condition by carrying the injection rate.

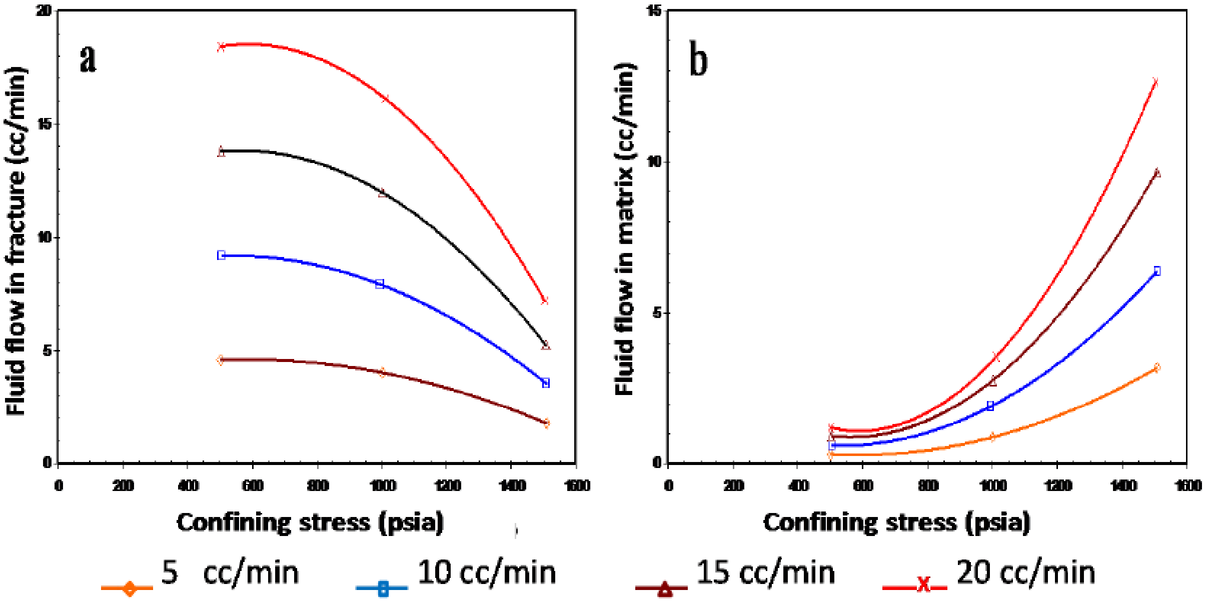


Figure 7 : Effect of stress on fluid flow in fracture and matrix at different injection rate (Muralidharan et al., 2005)

A recent numerical study by Fakcharoenphol *et al.* (2012) shows that, waterflooded-induced stress change improves oil recovery in shale reservoirs. The synergestic effect of reservoir cooling and pore pressure increase during water flooding can significantly trigger rock failure, potentially reactivating healed natural fractures and creating new micro-fractures (Figure 2). The micro fractures could create flow paths for hydrocarbons inside the matrix, and thus improving the fracture-matrix interface area and increasing hydrocarbon production from the matrixes. Likewise, analytic study by Kocabas (2006) shows that, in porous medium with stiff materials such as carbonate reservoir, cooling by water-flooding creates large scales tensile stress and may induce new fractures or propagate existing ones far into the reservoir.

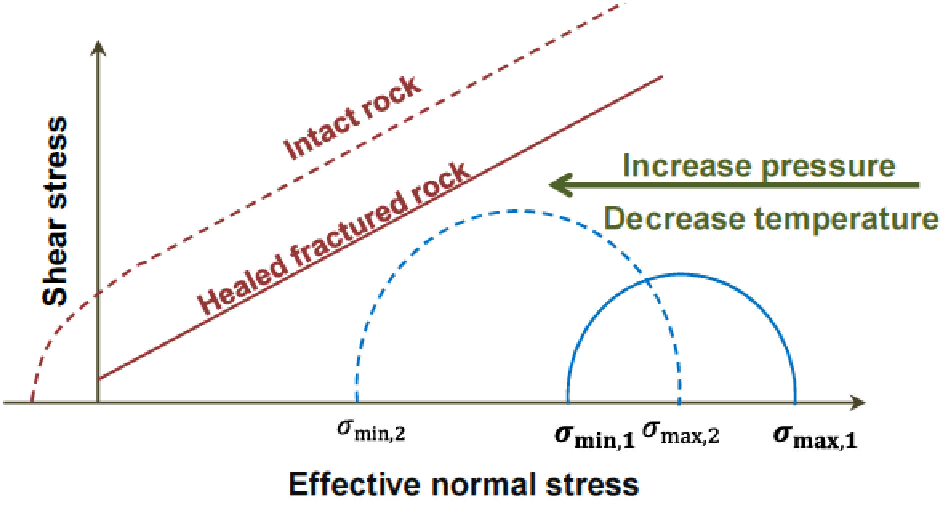


Figure 8 : Mohr diagram for stress change during water injection (Fakcharoenphol et al, 2012).

The Mohr circle is used to determine graphically the stress components acting on rotated coordinate or acting on a differently oriented plane passing through that point.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

The methodology of the research will be explained in flow chart below. The flow chart will cover the flow research for the whole project duration (FYP1 & FYP2). The reason of the methodology is to build an organized and manageable approach in term of time frame, cost and feasibility of the research.

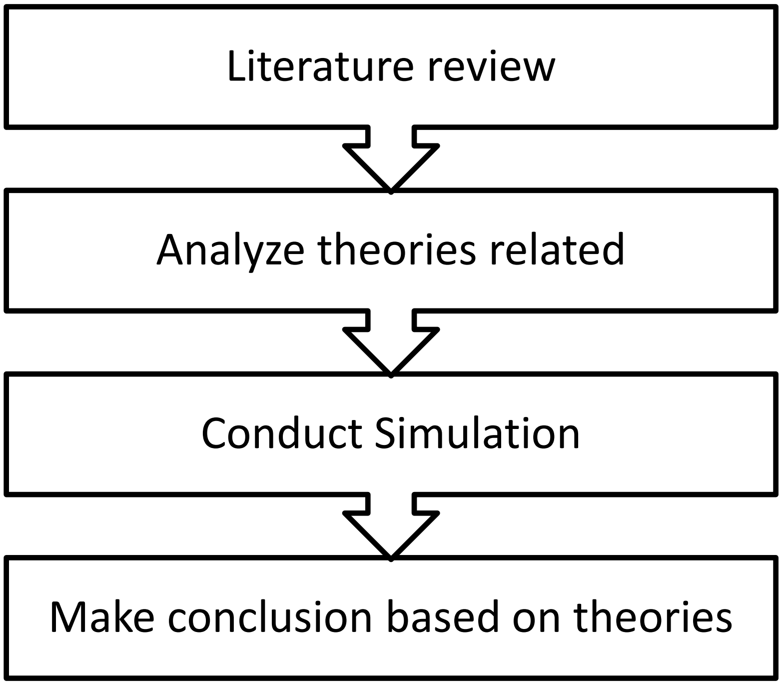


Figure 9 : Methodology flow chart

In literature review section, information related to geomechanical stress distribution is collected from books, journals, articles and internet. The information is studied and theories related are analyzed to have a better understanding on stress distribution in injection well. To develop a model on stress distribution, Petrel and Eclipse software are required. Simulation will be conducted using the software using data available at injection well. One way coupling will be used in this simulation, where

Eclipse will compute data like change in pressure, change in temperature, saturation of water, gas and oil. On the other hand, Petrel will only compute stress and strain condition. In other words, Eclipse is used to study the rock mechanical properties such as Young's modulus and Poisson ratio while Petrel will simulate reservoir approach for the water injection well. The reservoir approach includes parameters such as formation pressure with respect to depth, fracture formation pressure, and bottom-hole pressure. After the simulation is done, a correlation between reservoir and geomechanical parameter can be develop to determine initial stress condition at reservoir, and the optimum water injection rate.

The time give to complete the research is approximately 6 months and steps to complete the project are summarized in research methodology. In order to complete the project, a huge amount of studies and work is needed. References such as journal, books and articles related are needed to understand the fundamental of the topic selected. Detailed studies of the scope choose will need a simulation to prove the theory learned. For this project, Petrel and Eclipse are required to run simulation on geomechanical stress distribution in water injection well. The software is available at Universiti Teknologi PETRONAS. Below are the work flow charts for both study case in this project.

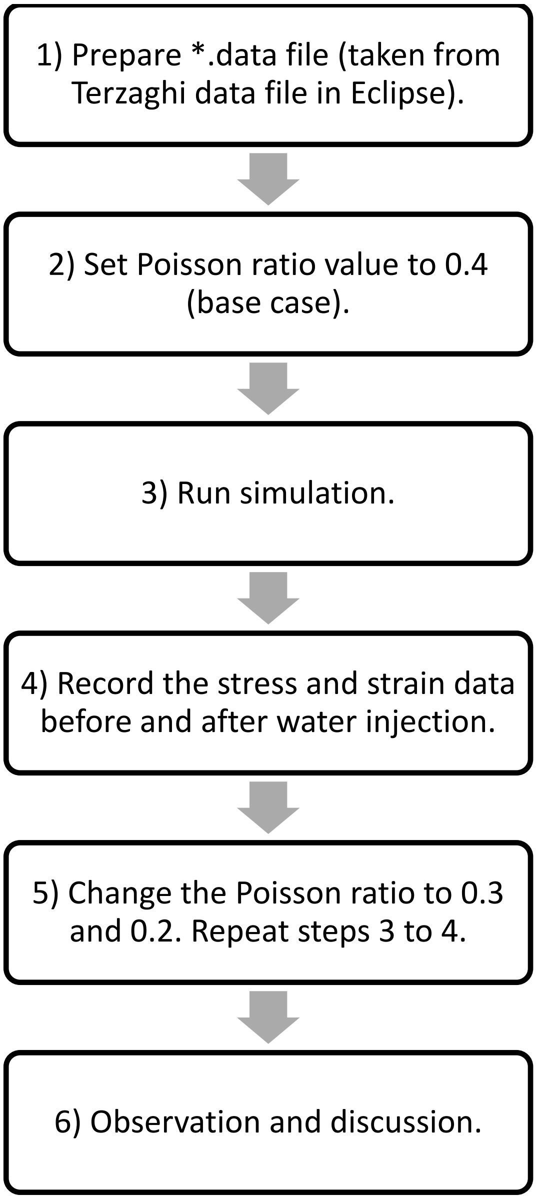


Figure 11 : Poisson's ratio work flow

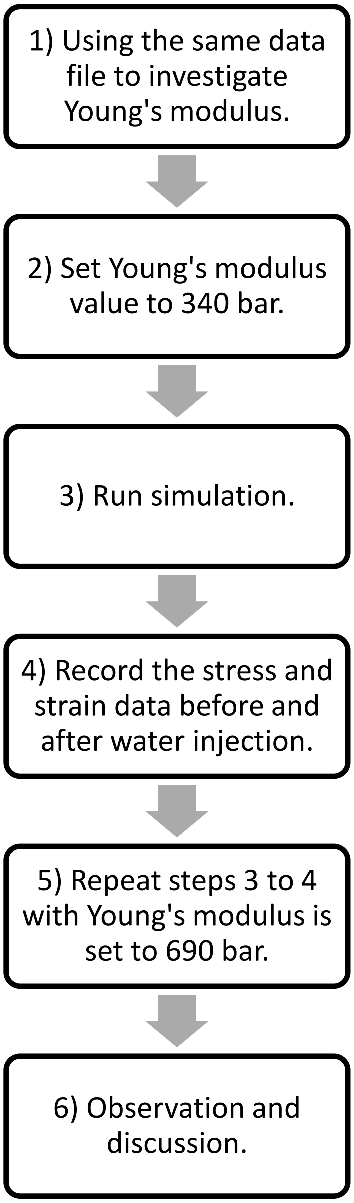


Figure 10 : Young's modulus work flow

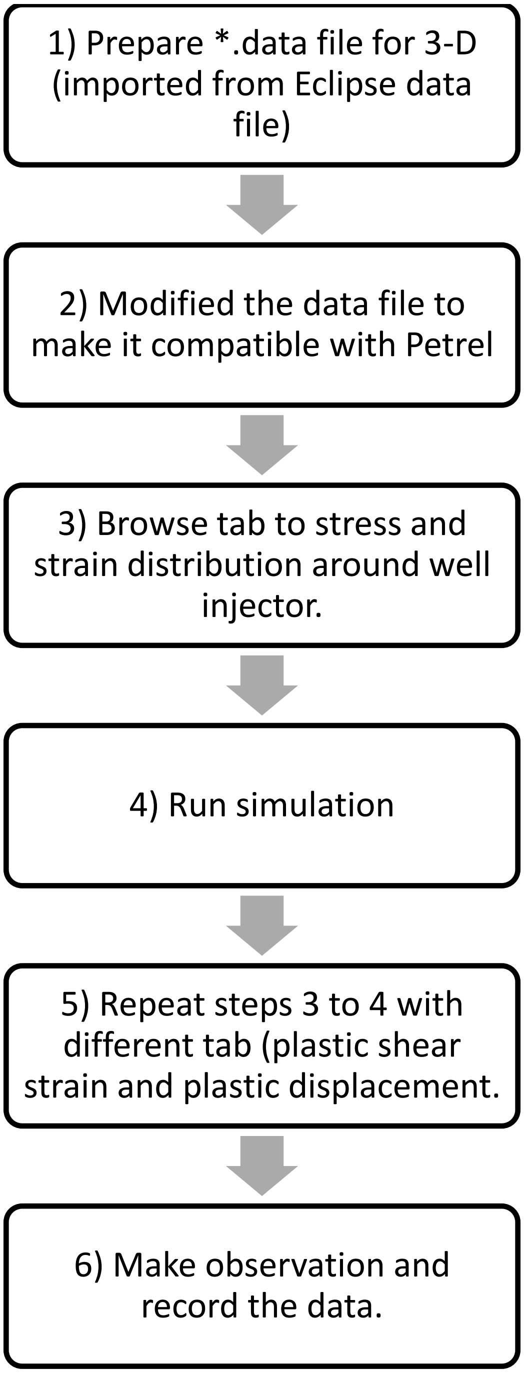


Figure 12 : Three dimensional reservoir approach work flow

3.2 KEY MILESTONE

Milestone	Week
Early Research Development • Research background • Scope of studies and Assumptions • Getting support from industry	1 - 9
Middle Research Development • Detailed research • Developing the theory • Data gathering • Testing the theory • Research Simulation	10 - 21
Final Research • Finalizing the simulation • Completing the documentation	22 - 26

Table 1 : Key milestone

3.3 GANTT CHART

Phase	**FYP 1**													**FYP 2**												
	Weeks																									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**
Finalizing Topic of Project	■	■	■																							
Background Research **Extended Proposal**			■	■	■	■																				
Proposal Defense Detailed Research						■	■	■	■																	
Developing Theory & Data Gathering									■	■	■	■	■	■	■	■	■									
Develop Simulation **Interim Draft Report**															■	■	■	■	■	■	■	■				
Analysing the result Finalizing Simulation																					■	■	■	■	■	■

Table 2- Gantt Chart

Chapter 4

RESULT AND DISCUSSION

4.1 RESULT

The study is divided into two parts; first part is to investigate in term of wellbore approach of the water injection well. In this approach, elastic deformation is investigated by manipulating the value of Poisson's ratio and Young's modulus. The changes in values of these parameters will result in different stress and strain distribution around the water injection well before and after the water injection. Poisson's ratio value is investigated at 0.2, 0.3 and 0.4, and observation is made. Using the same data file, Young's modulus value is investigated at 340 bar and 690 bar at base case, which the Poisson's ratio value is 0.3.

In the second part of the study is to investigate in term of reservoir approach of the water injection well. Both elastic and plastic deformation is investigated in reservoir approach. Elastic deformation is simulated by observing the changes in stress and strain distribution before and after water injection. On the other side, plastic deformation is investigated by observing the changes in plastic strain distribution, volumetric plastic strain, and wellbore integrity around the well before and after water injection.

4.1.1 INVESTIGATING THE EFFECT OF POISSON'S RATIO ON STRESS AND STRAIN CHANGES:

a) Poisson ratio equals to 0.3

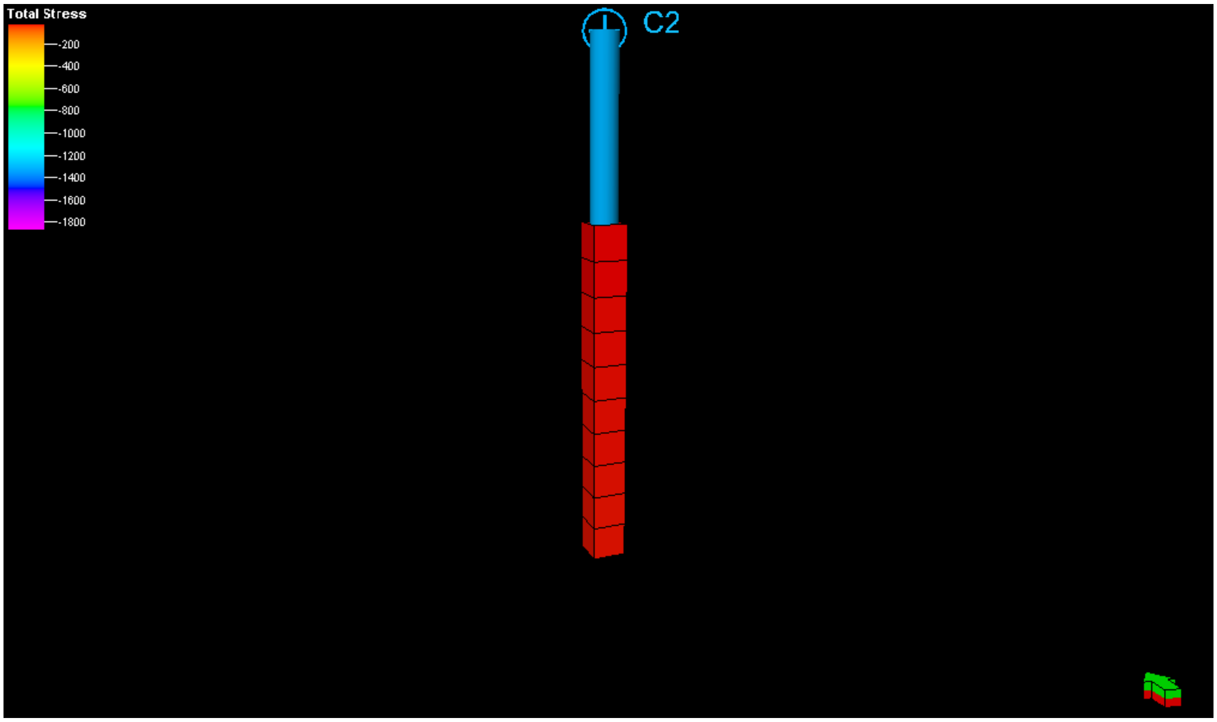


Figure 13 : Initial stress condition before injections (value : -24.43)

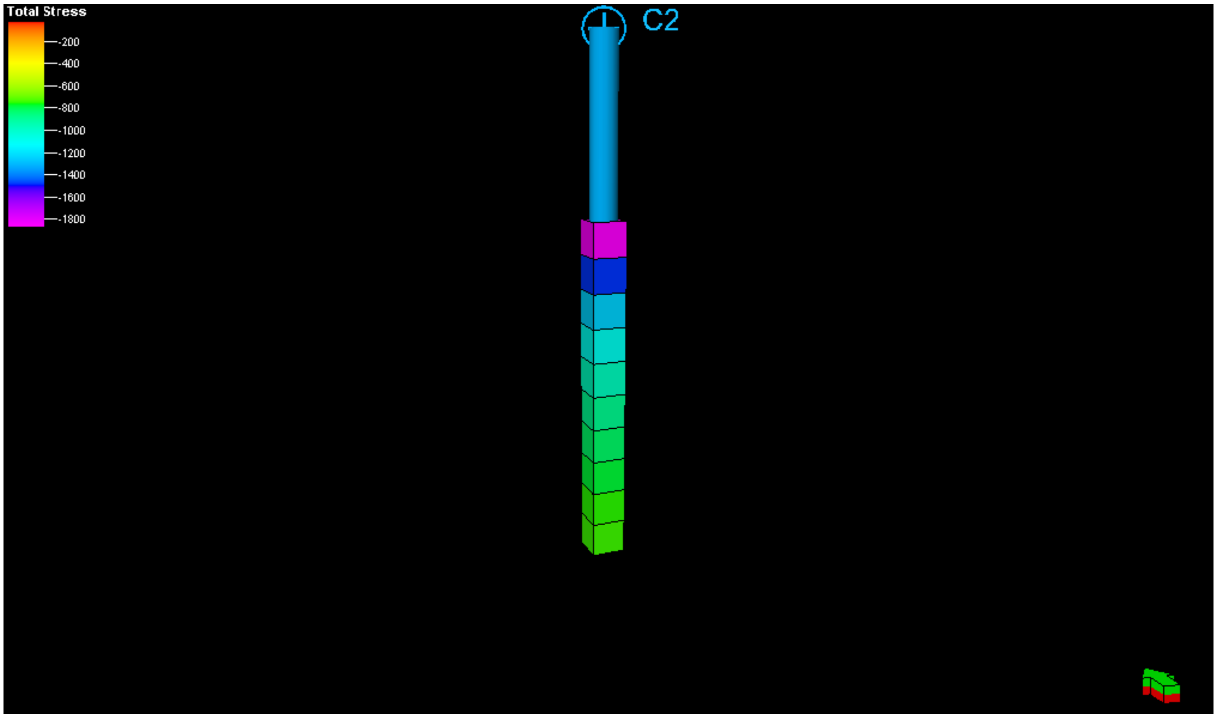


Figure 14 : Final stress condition after injection (value : -1865.20)

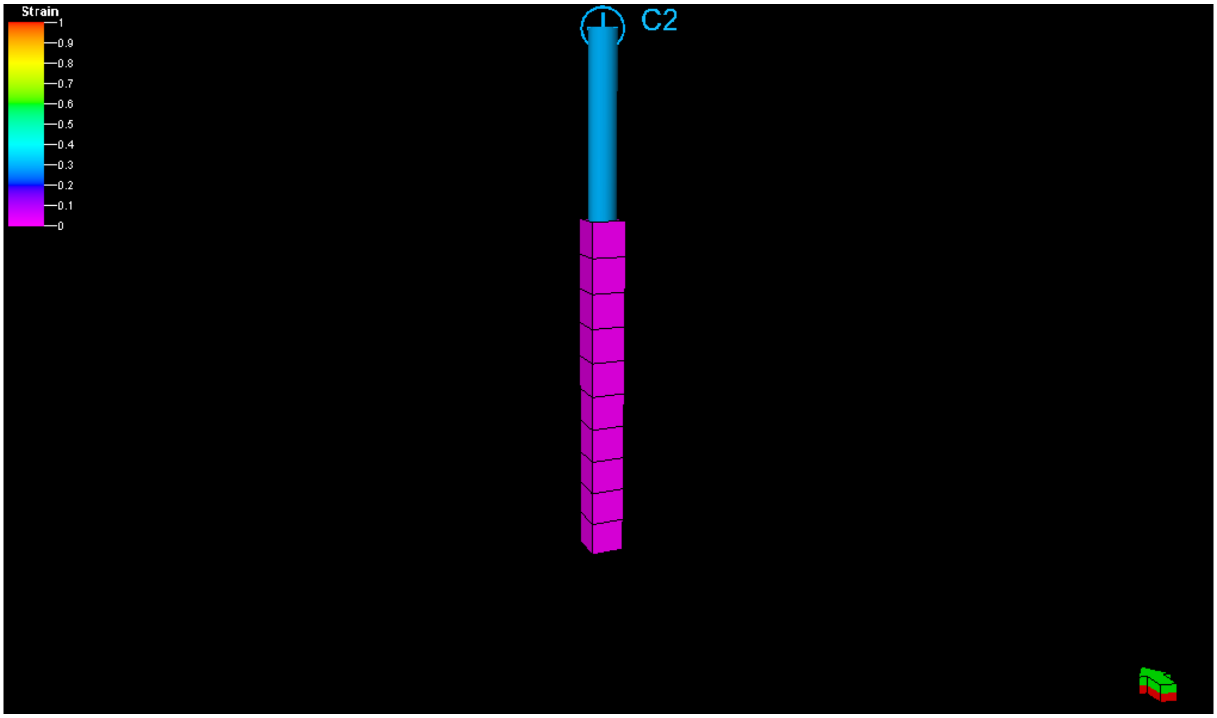


Figure 15: Initial strain condition before injection. (value : -1.010550e-015)

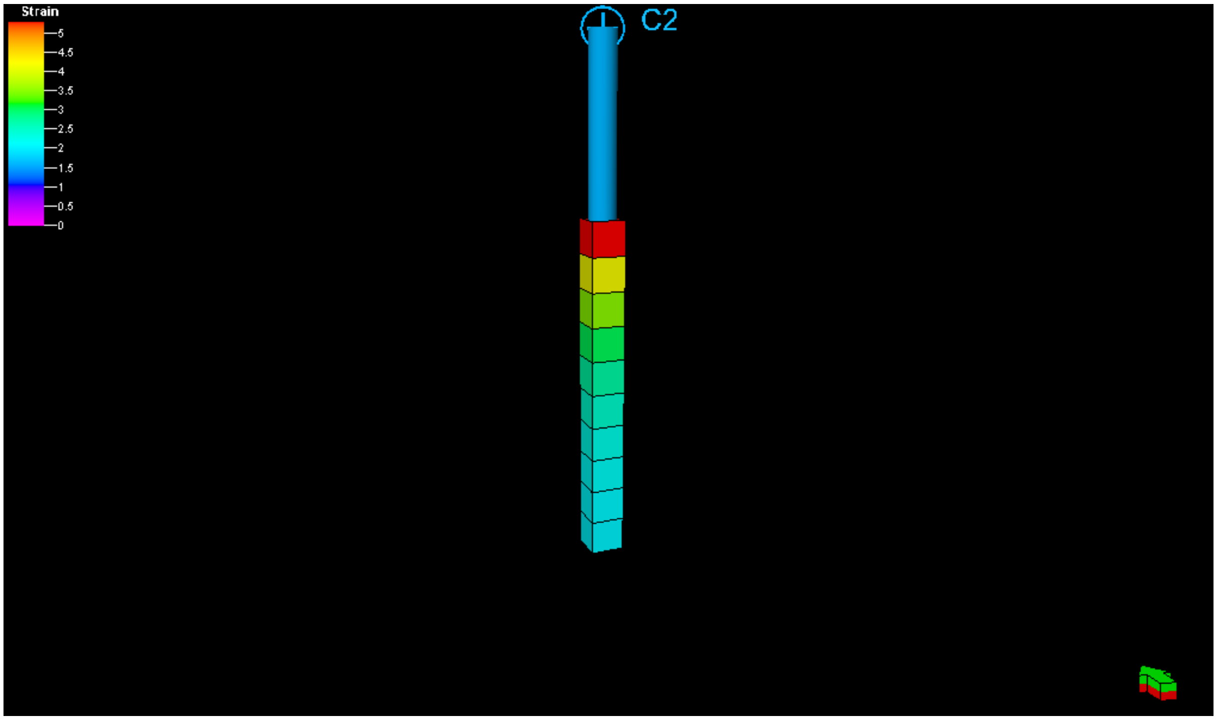


Figure 16 : Final strain condition after injection. (value : -0.0167)

b) Poisson ratio equals to 0.4

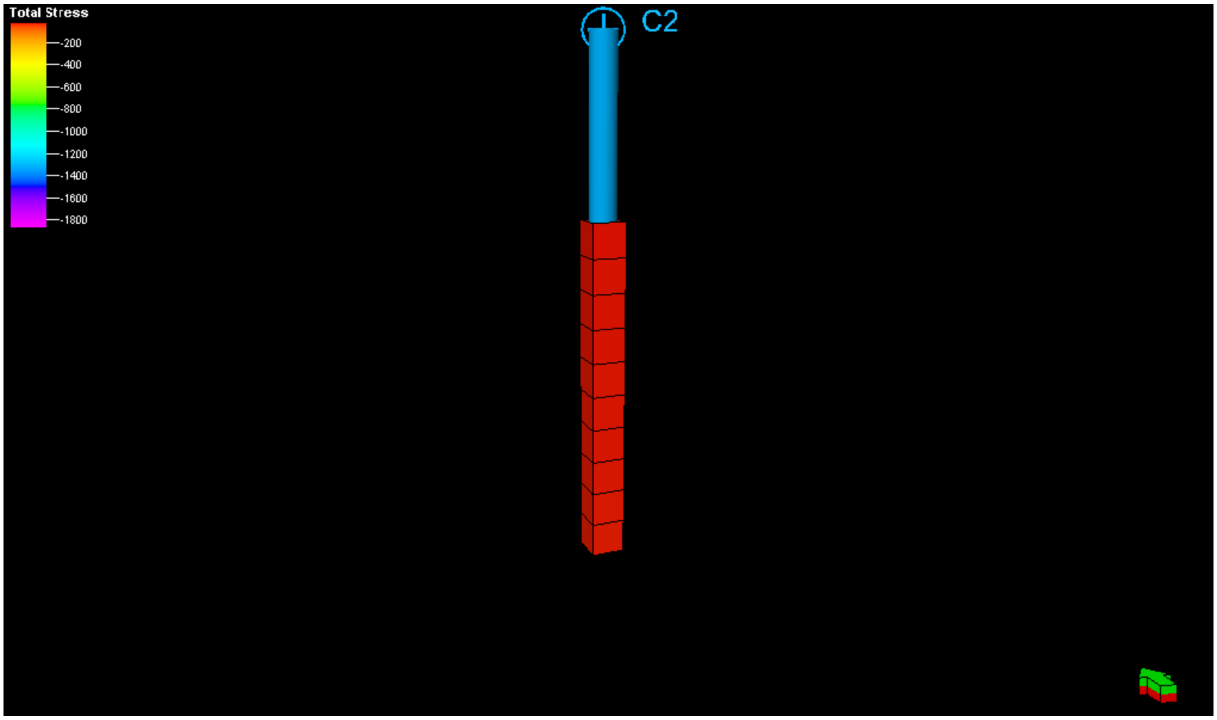


Figure 17: Initial stress condition before injection. (value : -26.83)

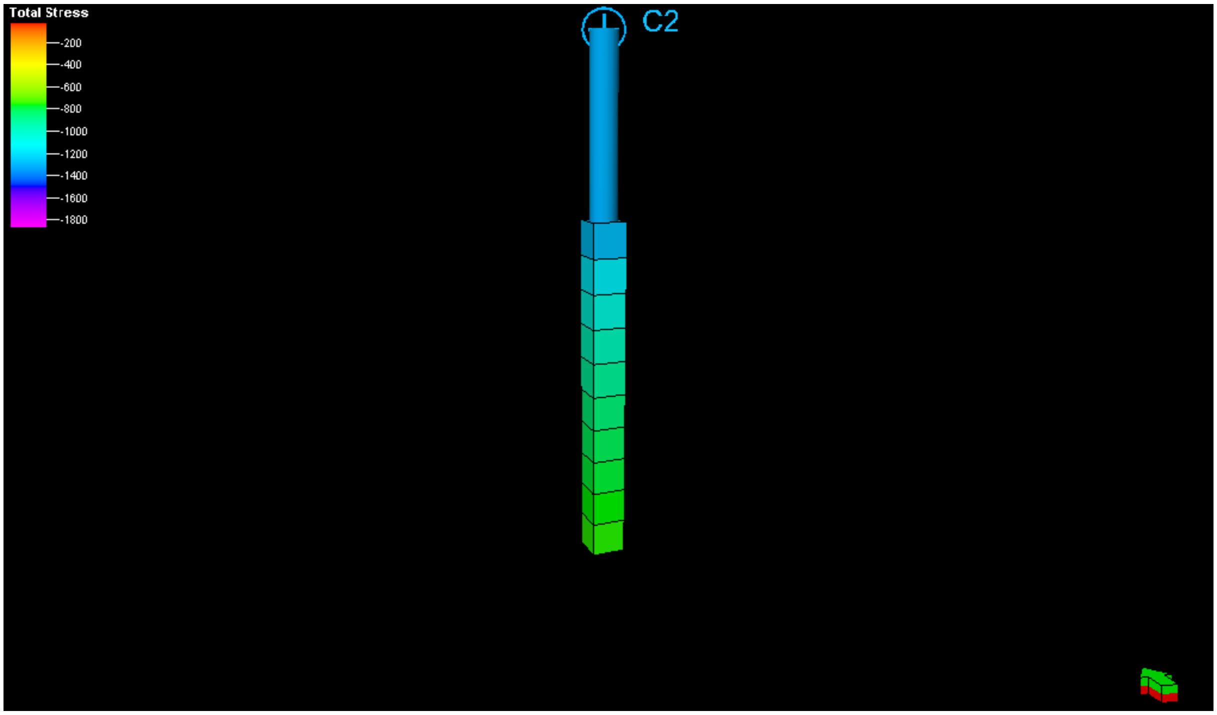


Figure 18 : Final stress condition after injection. (value : -1279.52)

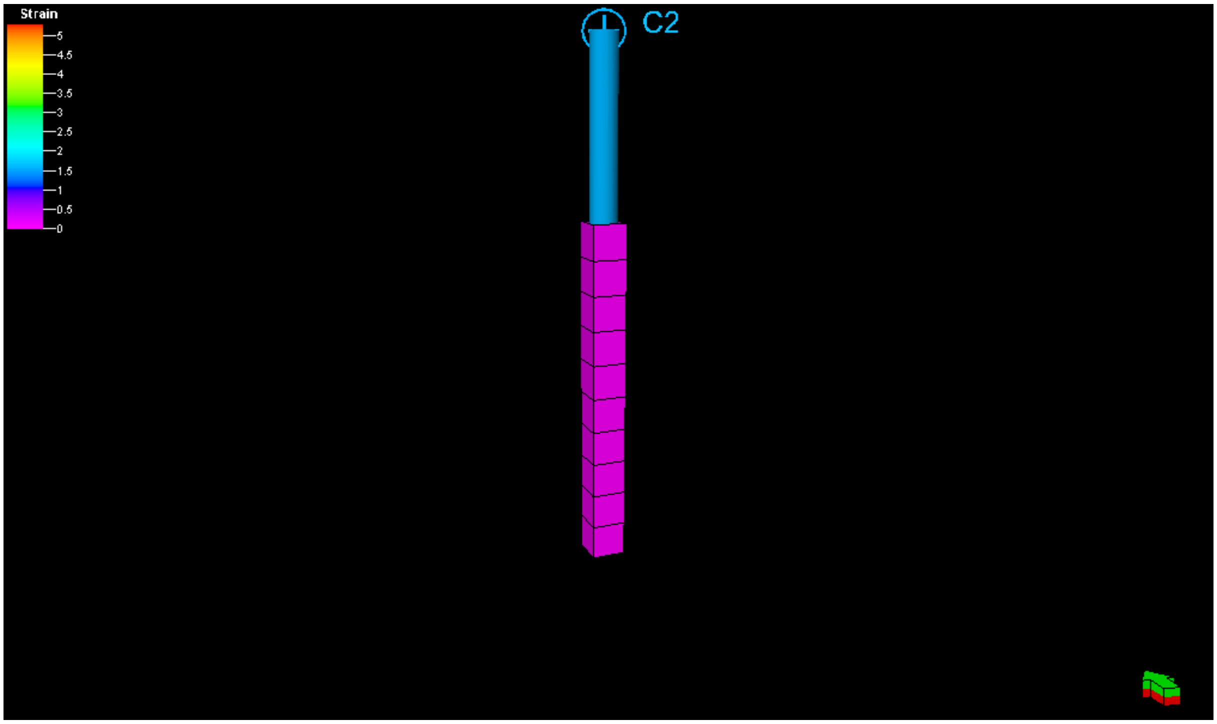


Figure 19 : Initial strain condition before injection. (value : -0.0105)

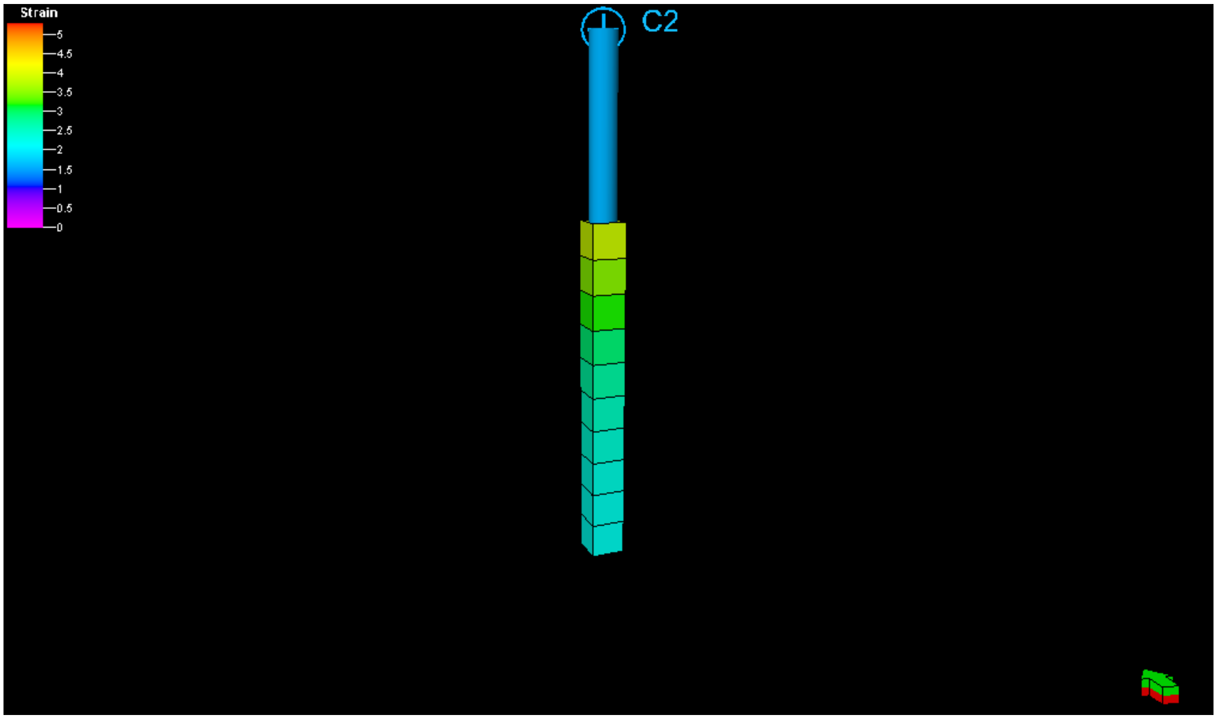


Figure 20 : Final strain condition after injection. (value : 3.8869)

c) Poisson's ratio equals to 0.2.

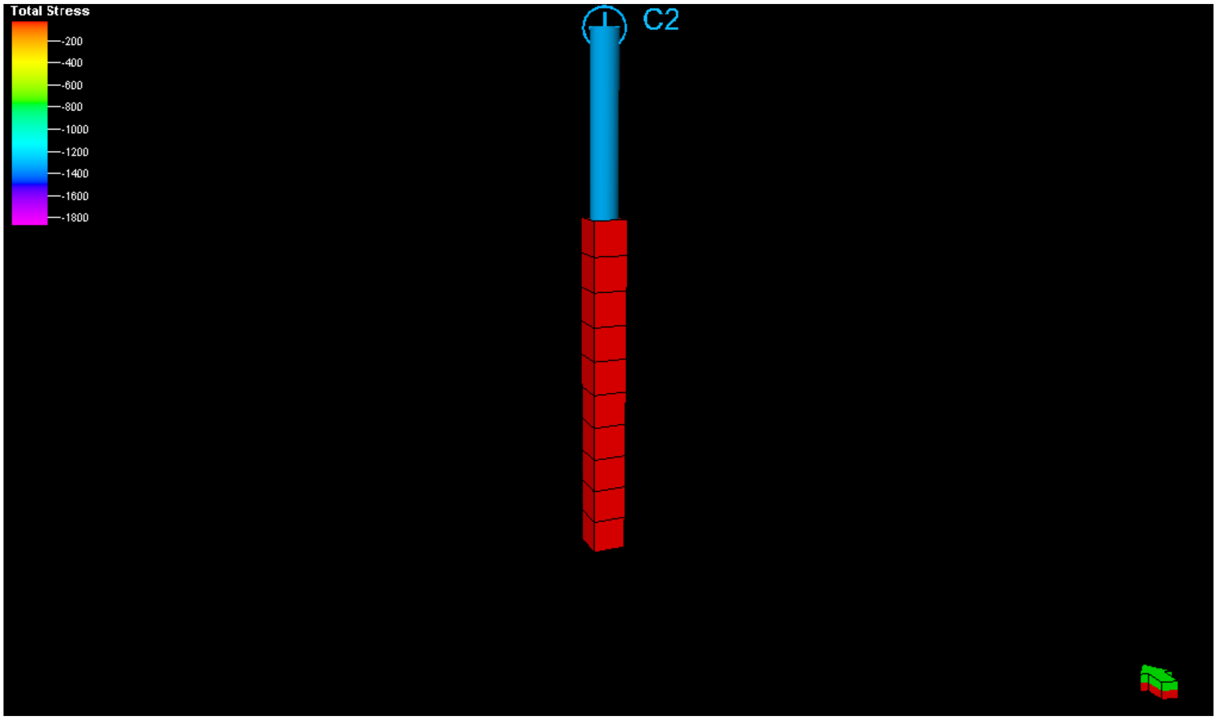


Figure 21: Initial stress condition before injection. (value : -22.62)

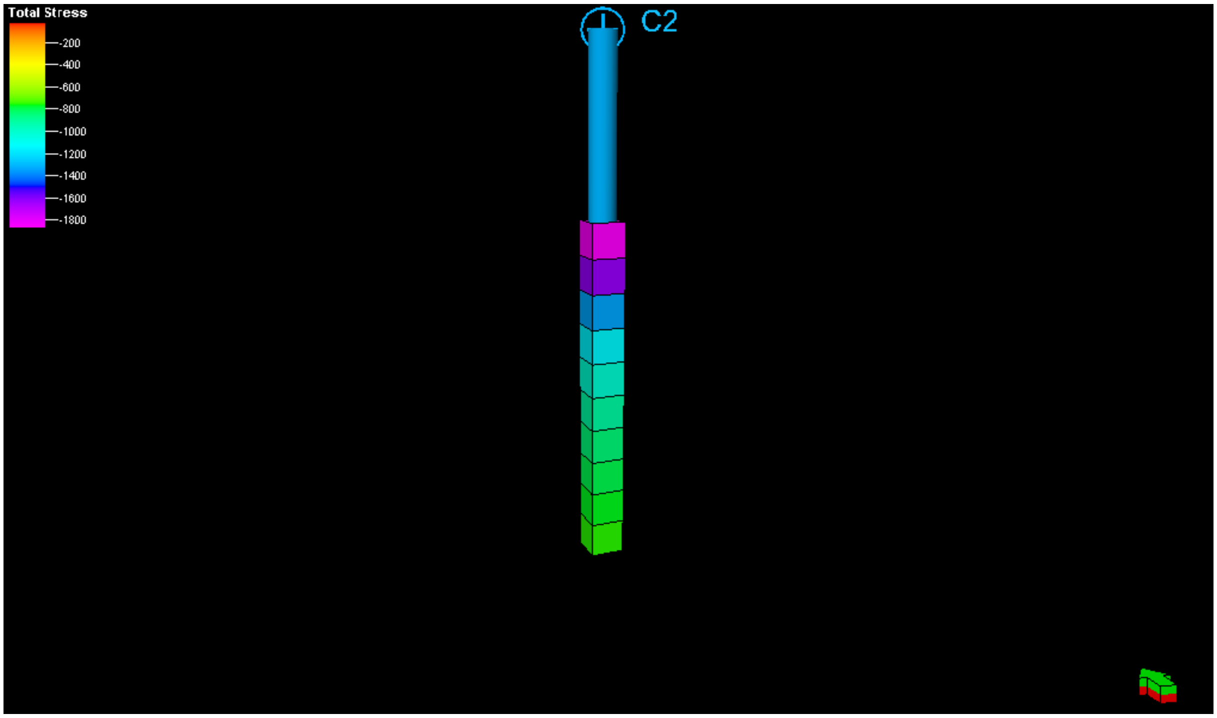


Figure 22 : Final stress condition after injection. (value : -2161.78)

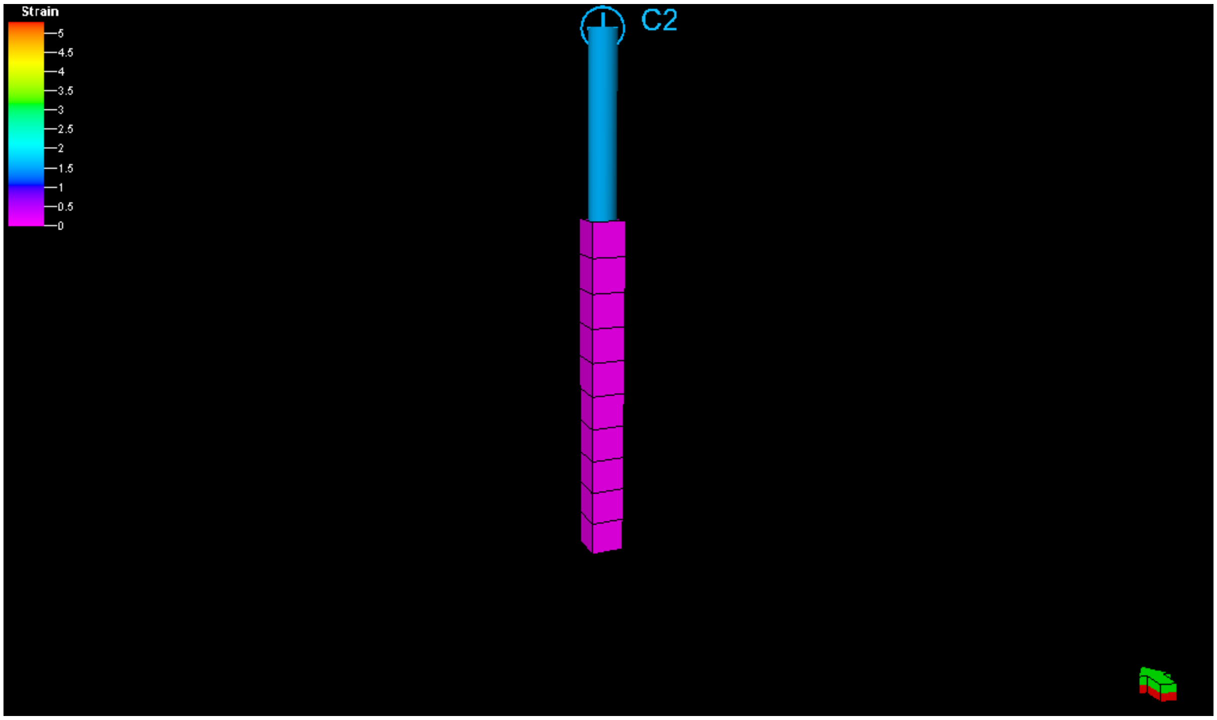


Figure 23 : Initial strain condition before injection. (value : -0.0202)

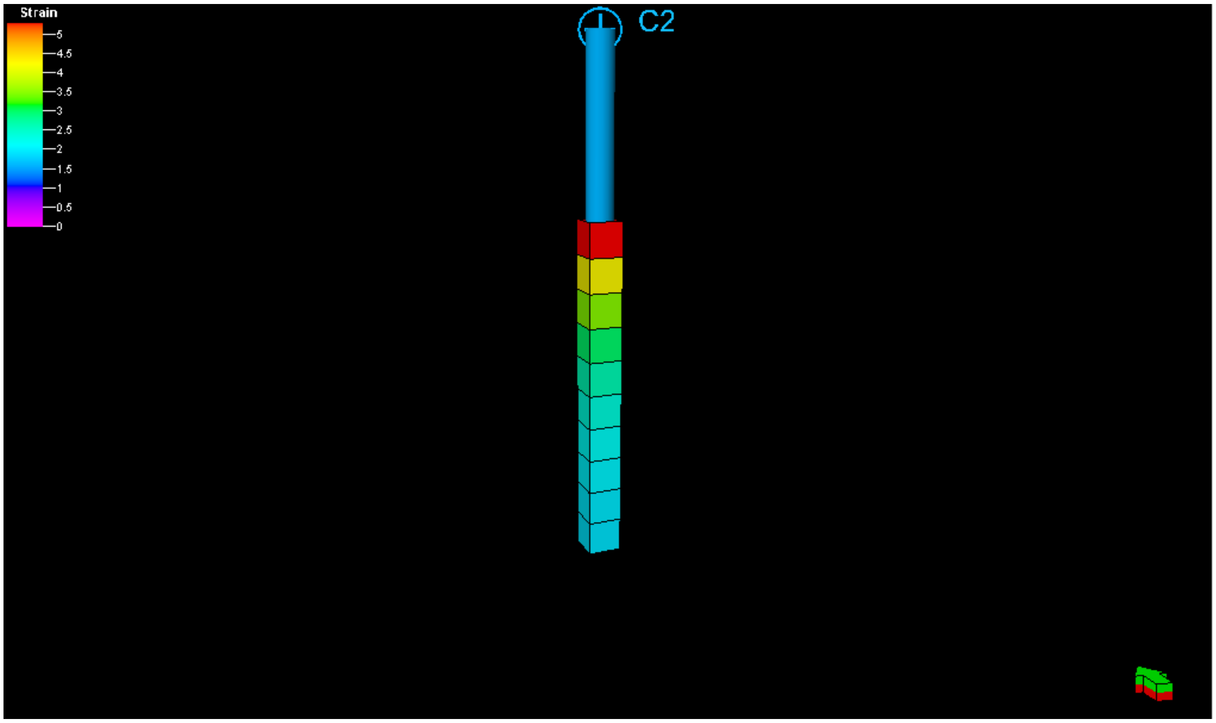


Figure 24 : Final strain condition after injection. (value : 5.6844)

4.1.2 INVESTIGATING THE EFFECTS OF YOUNG'S MODULUS ON STRESS AND STRAIN CHANGES:

a) Young's modulus equals to 340 bar.

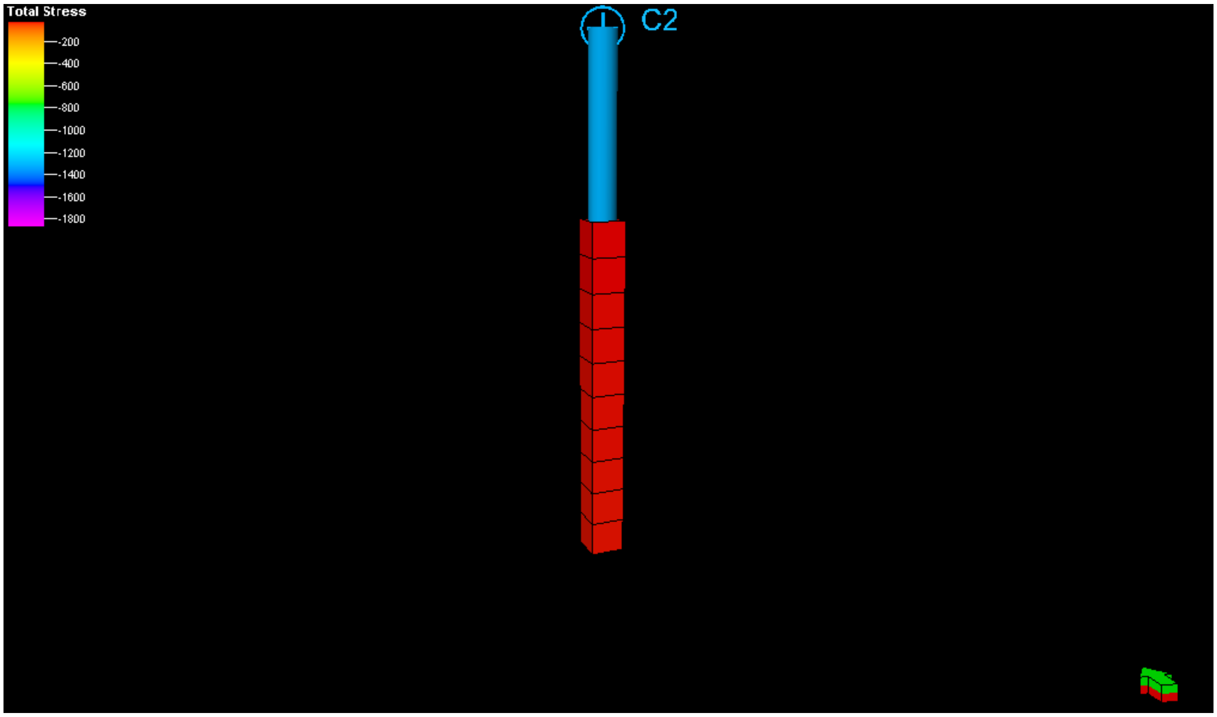


Figure 25 : Initial stress condition before injection. (value : -24.43)

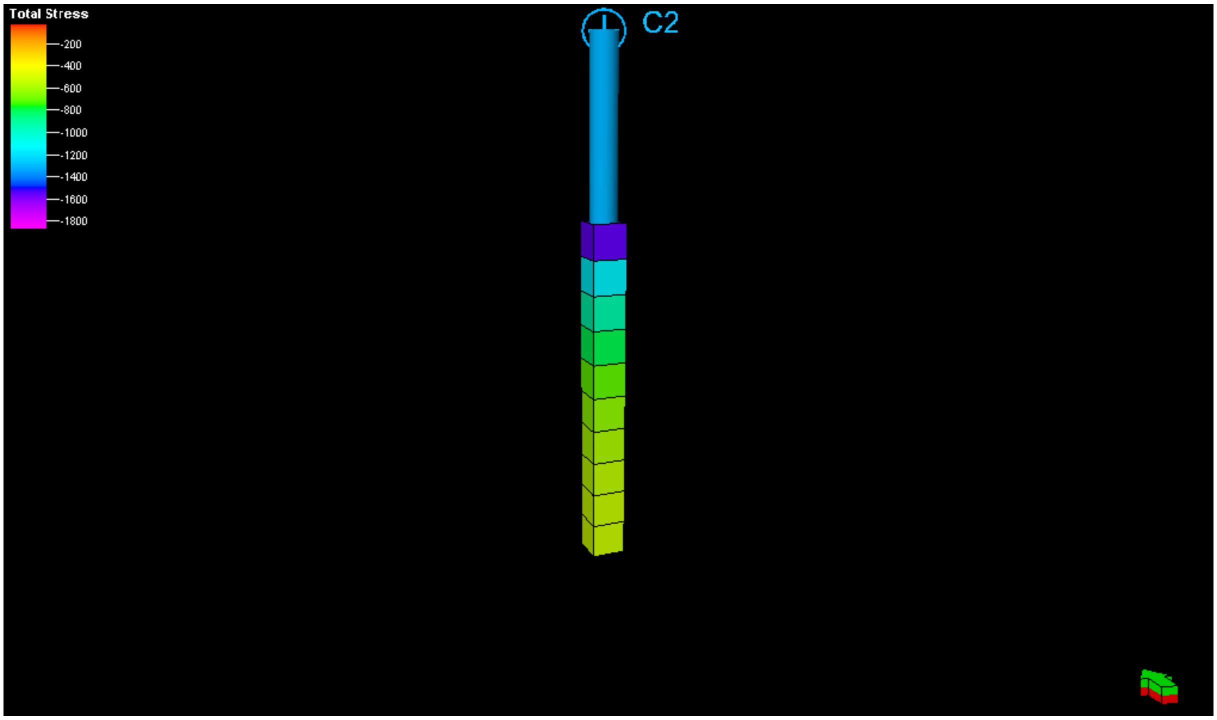


Figure 26 : Final stress condition after injection. (value : -1554.45)

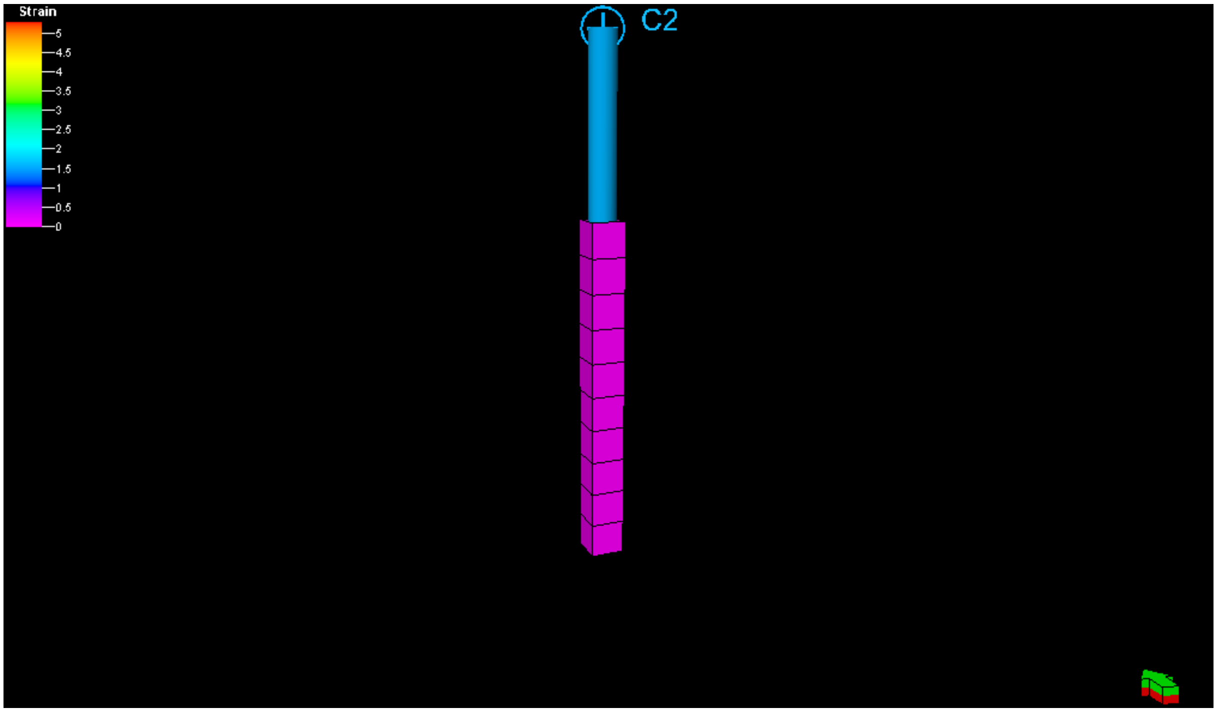


Figure 27 : Initial strain condition before injection. (value : -0.0221)

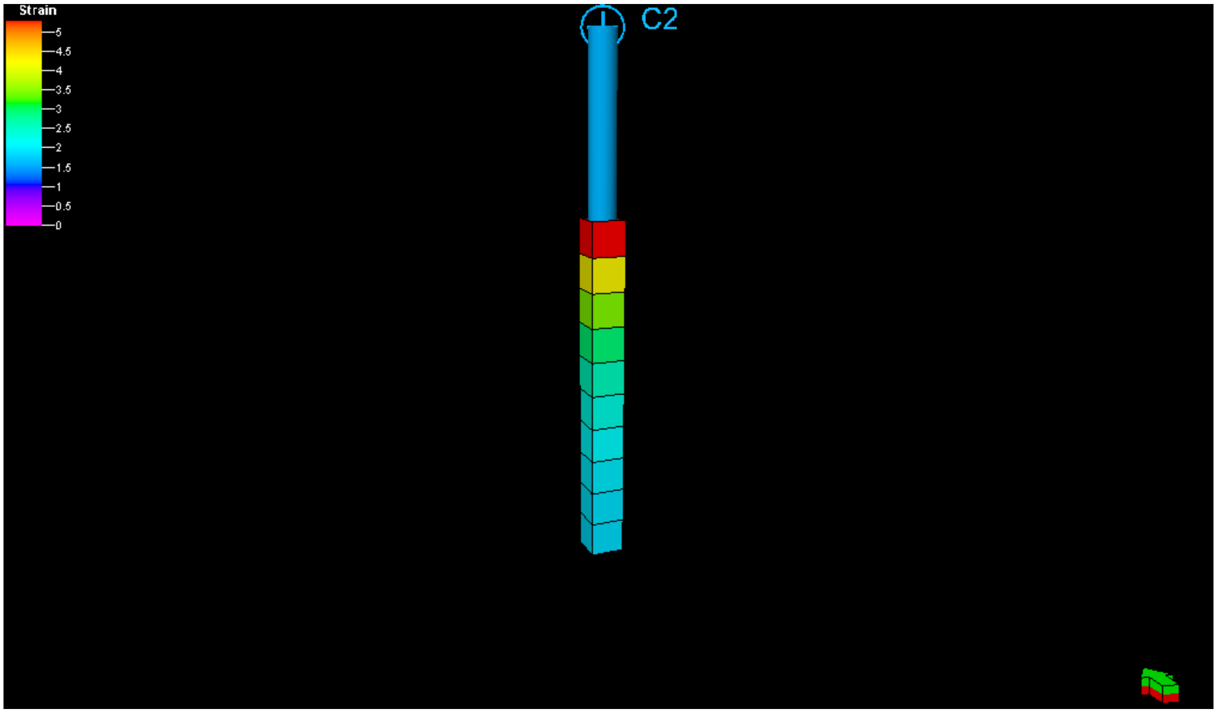


Figure 28 : Final strain condition after injection. (value : 5.8282)

b) Young’s modulus equals to 690 bar.

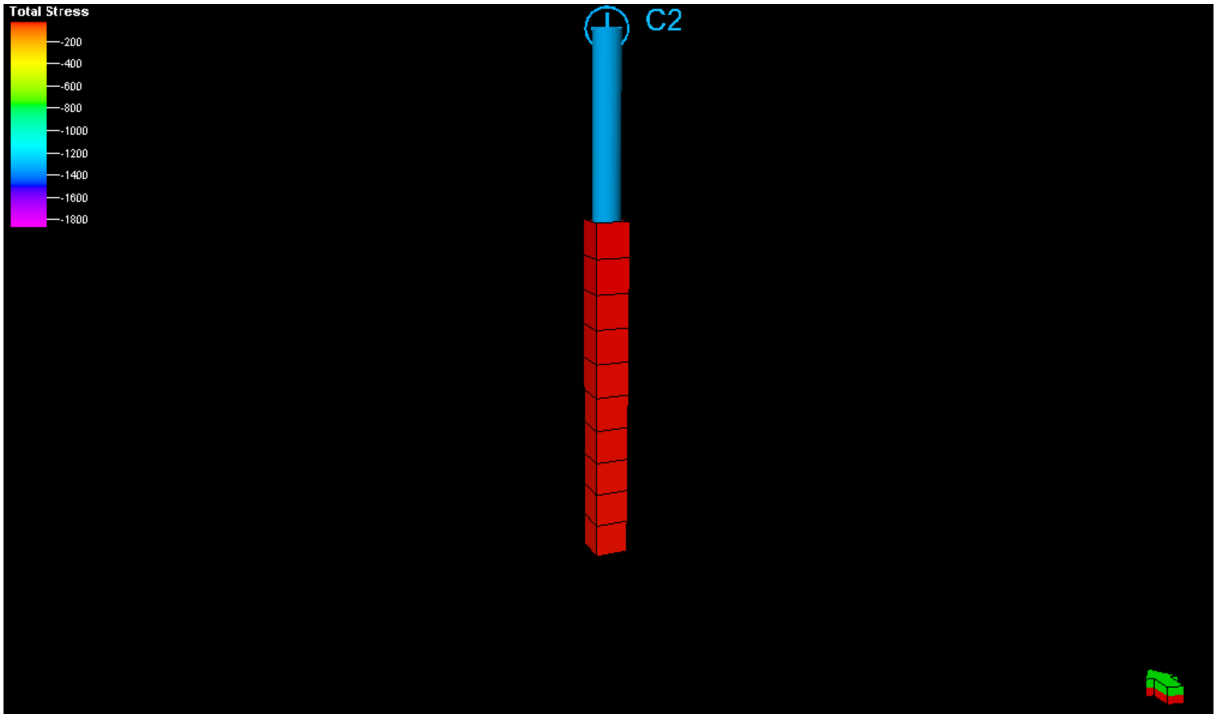


Figure 29 : Initial stress condition before injection. (value : -24.43)

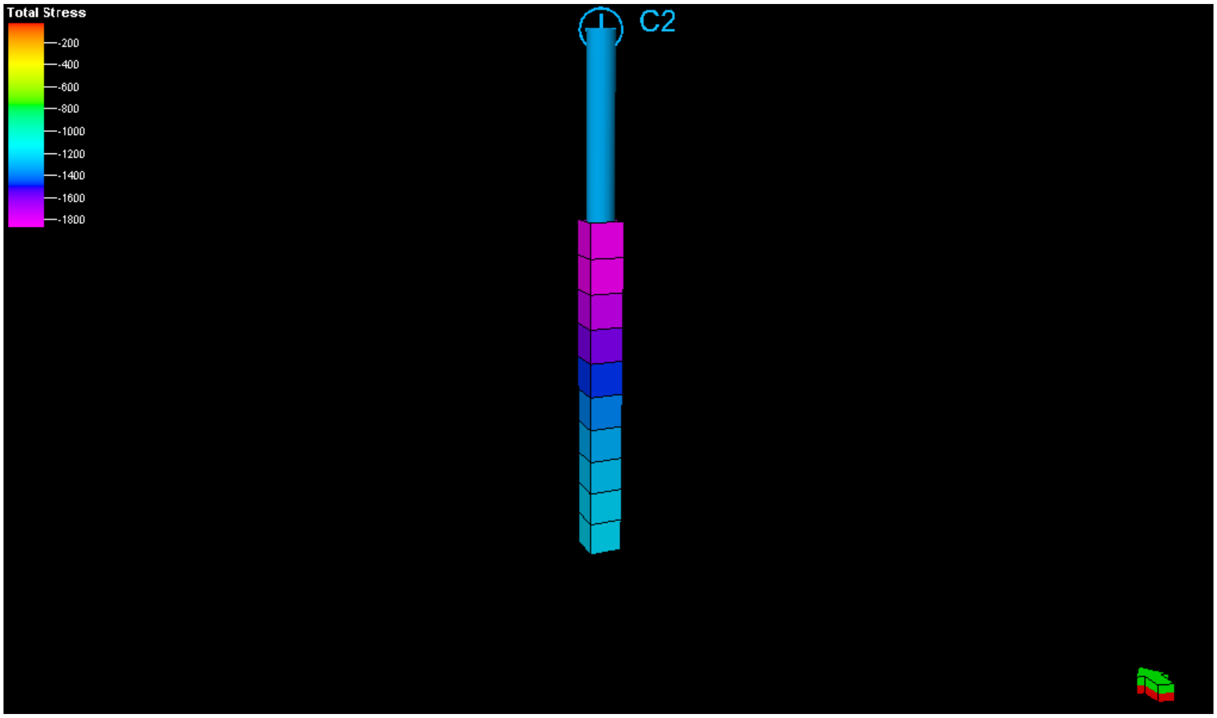


Figure 30 : Final stress condition after injection. (value : -2159.55)

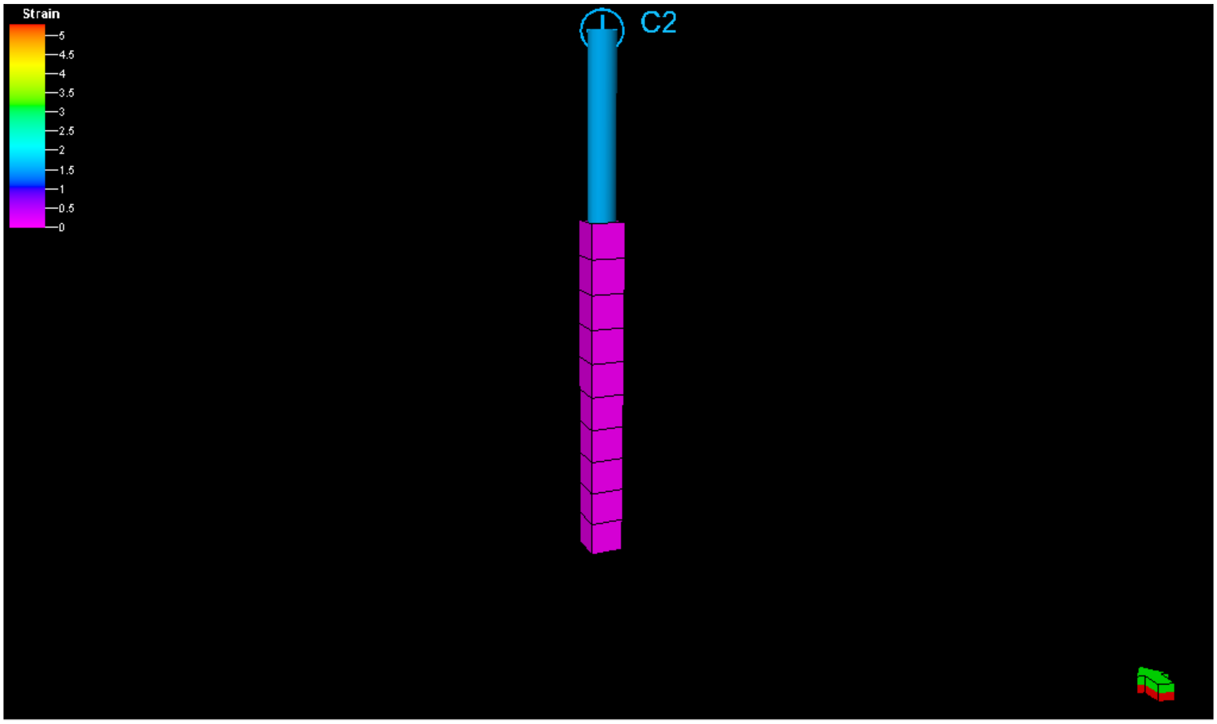


Figure 31 : Initial strain condition before injection. (value : -0.0109)

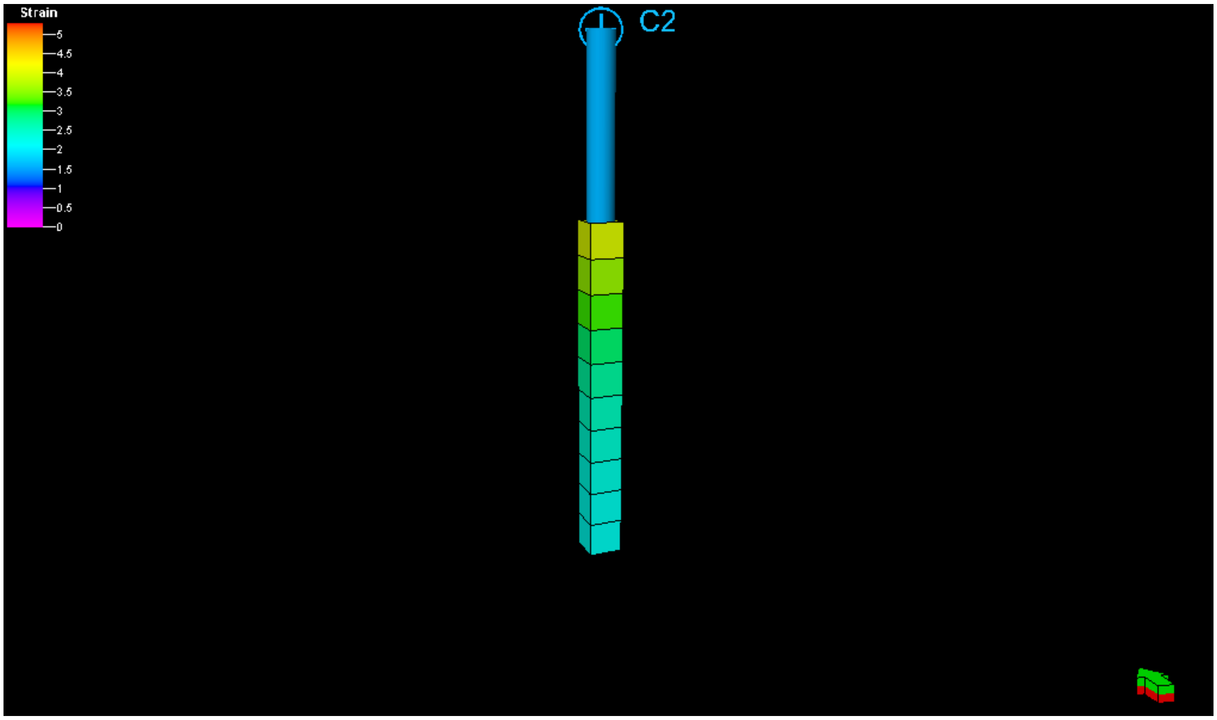
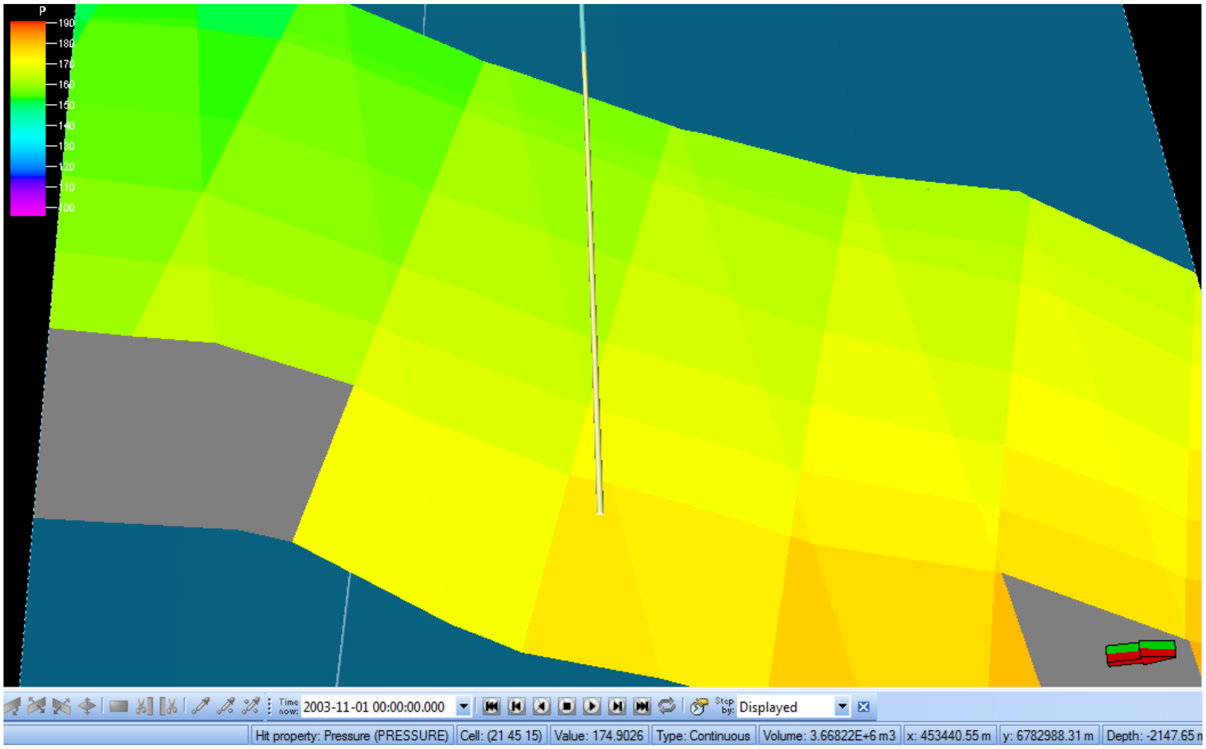


Figure 32 : Final strain condition after injection. (value : 4.0119)

4.2 INVESTIGATING THE FAILURE AROUND THE WATER INJECTOR BEFORE AND AFTER PROCESS:

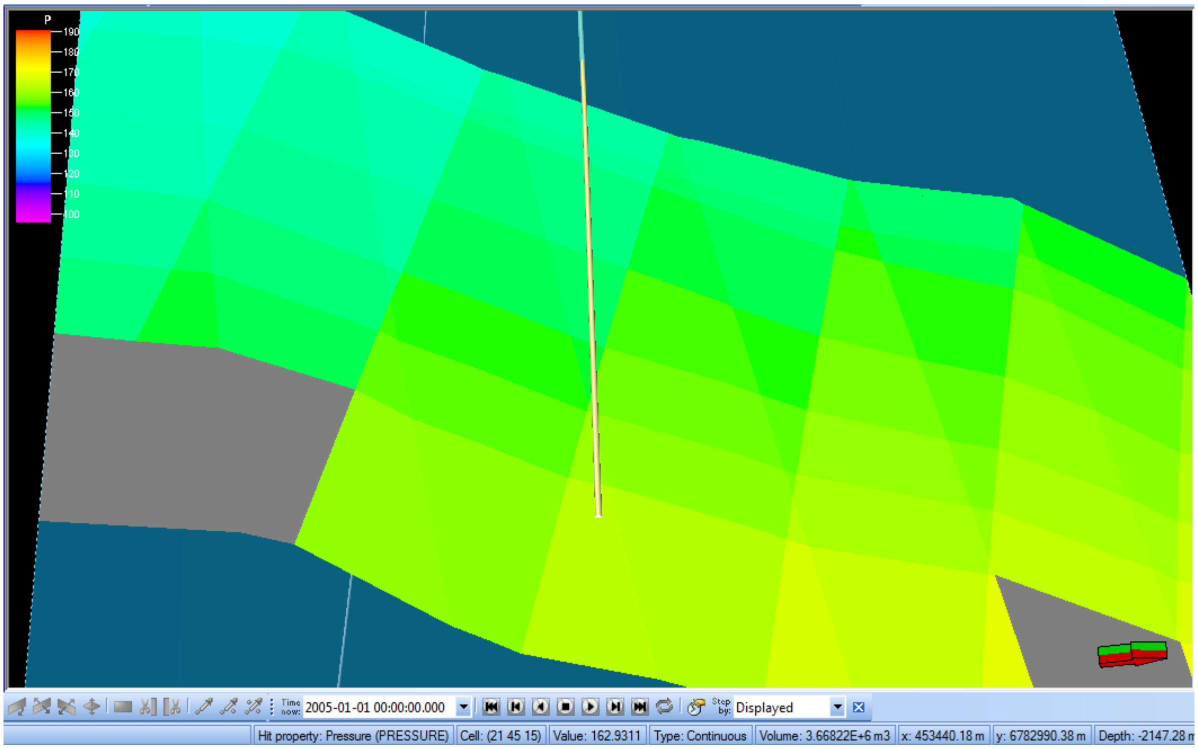


Time now: 2003-11-01 00:00:00.000

Step by: Displayed

Hit property: Pressure (PRESSURE) | Cell: (21 45 15) | Value: 174.9026 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453440.55 m | y: 6782988.31 m | Depth: -2147.65 m

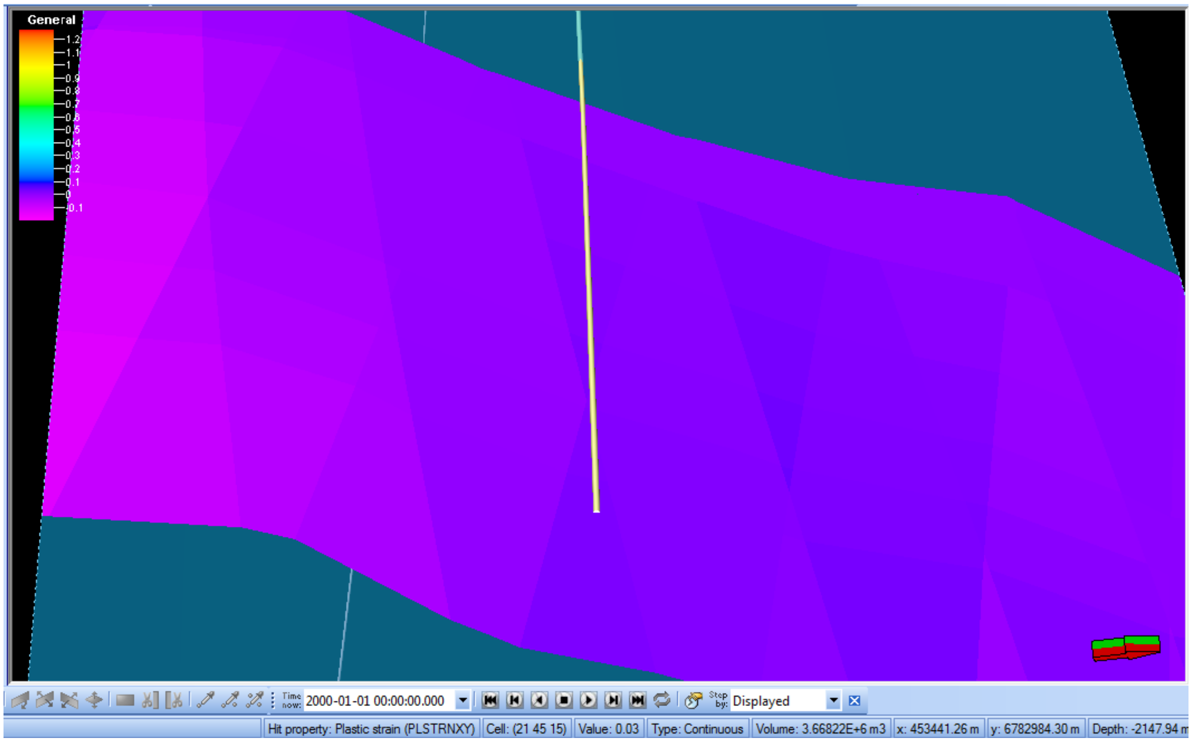
Figure 33 : Pressure around the injector before process.



Time now: 2005-01-01 00:00:00.000 | Step by: Displayed

Hit property: Pressure (PRESSURE) | Cell: (21 45 15) | Value: 162.9311 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453440.18 m | y: 6782990.38 m | Depth: -2147.28

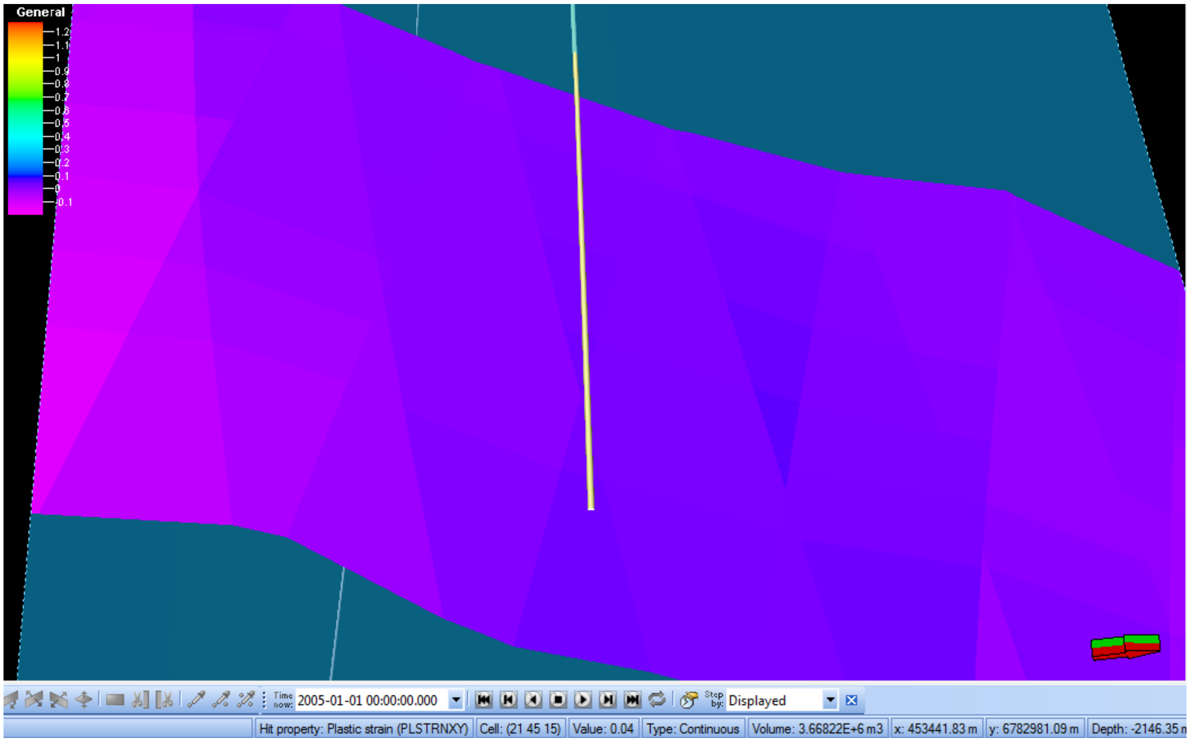
Figure 34 : Pressure around the injector after process. (decreasing up to 12bar)



Time now: 2000-01-01 00:00:00.000 | Step by: Displayed

Hit property: Plastic strain (PLSTRNXY) | Cell: (21 45 15) | Value: 0.03 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453441.26 m | y: 6782984.30 m | Depth: -2147.94

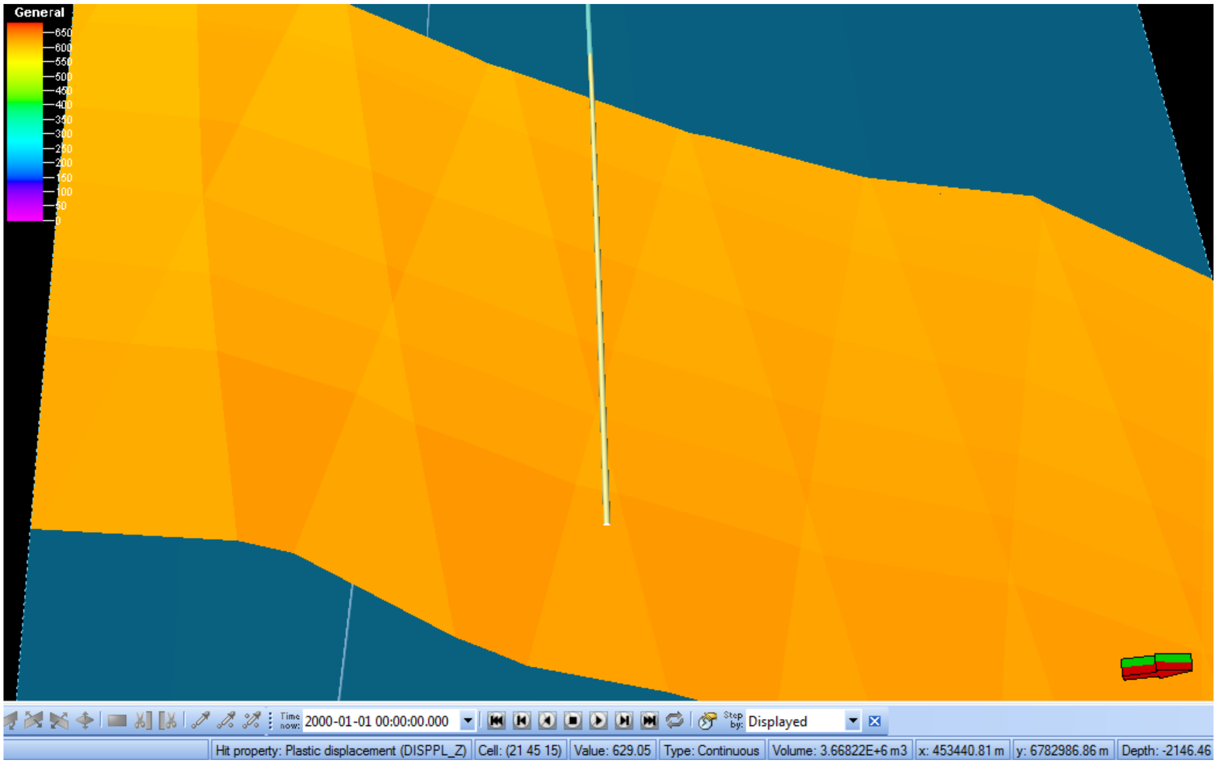
Figure 35 : Plastic shear strain before process. (value : 0.03)



Time now: 2005-01-01 00:00:00.000 | Step by: Displayed

Hit property: Plastic strain (PLSTRNXY) | Cell: (21 45 15) | Value: 0.04 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453441.83 m | y: 6782981.09 m | Depth: -2146.35

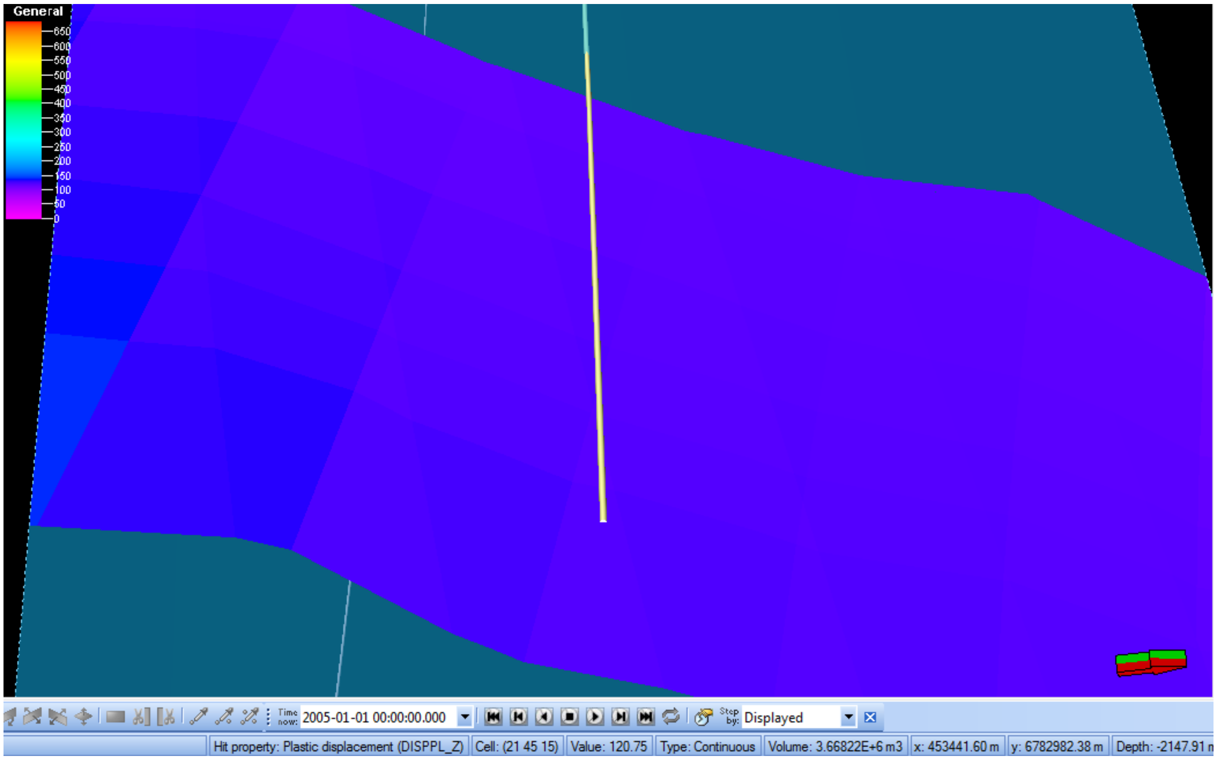
Figure 36 : Plastic shear strain after process. (value : 0.04)



Time now: 2000-01-01 00:00:00.000 | Step by: Displayed

Hit property: Plastic displacement (DISPPL_Z) | Cell: (21 45 15) | Value: 629.05 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453440.81 m | y: 6782986.86 m | Depth: -2146.46

Figure 37 : Plastic displacement before process.

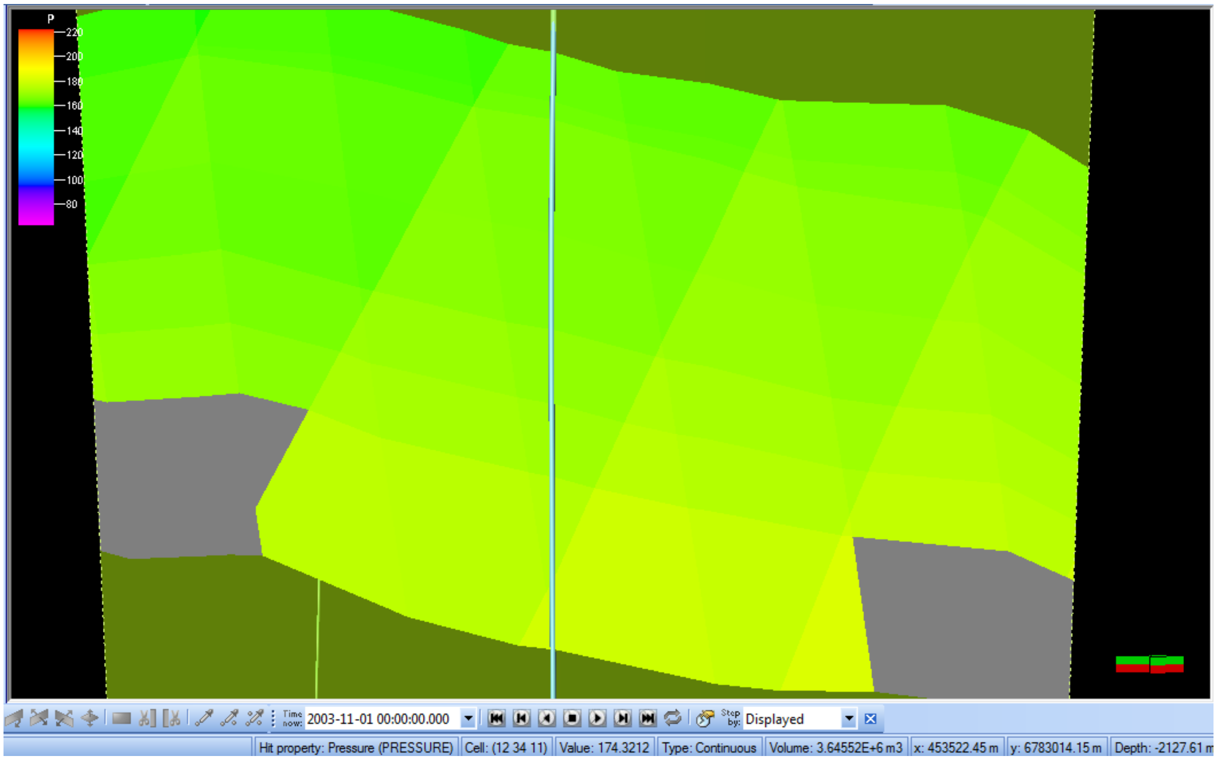


Time now: 2005-01-01 00:00:00.000

Step by: Displayed

Hit property: Plastic displacement (DISPPL_Z) | Cell: (21 45 15) | Value: 120.75 | Type: Continuous | Volume: 3.66822E+6 m3 | x: 453441.60 m | y: 6782982.38 m | Depth: -2147.91

Figure 38 : Plastic displacement after process.

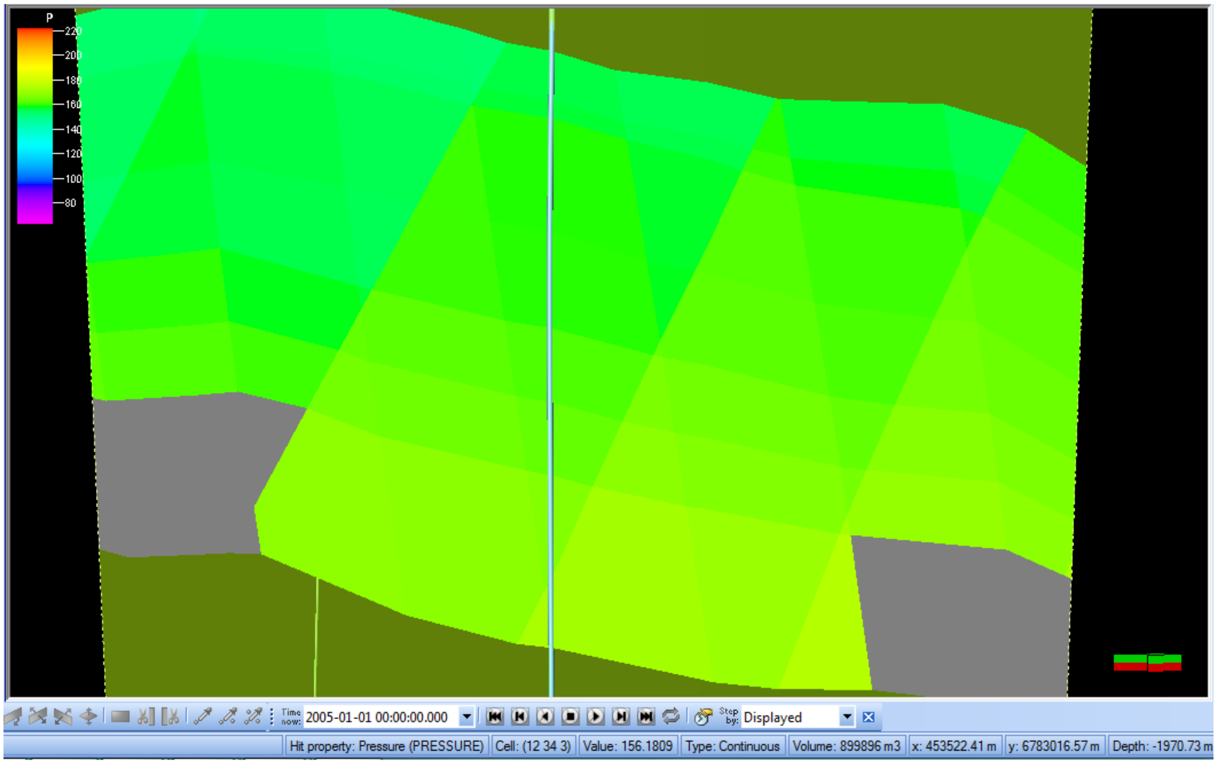


Time now: 2003-11-01 00:00:00.000

Step by: Displayed

Hit property: Pressure (PRESSURE) | Cell: (12 34 11) | Value: 174.3212 | Type: Continuous | Volume: 3.64552E+6 m3 | x: 453522.45 m | y: 6783014.15 m | Depth: -2127.61 m

Figure 39 : Pressure around the injector before production (without any water injections)



Time now: 2005-01-01 00:00:00.000

Step by: Displayed

Hit property: Pressure (PRESSURE) | Cell: (12 34 3) | Value: 156.1809 | Type: Continuous | Volume: 899896 m3 | x: 453522.41 m | y: 6783016.57 m | Depth: -1970.73 m

Figure 40: Pressure around the injector after production (without any water injections)

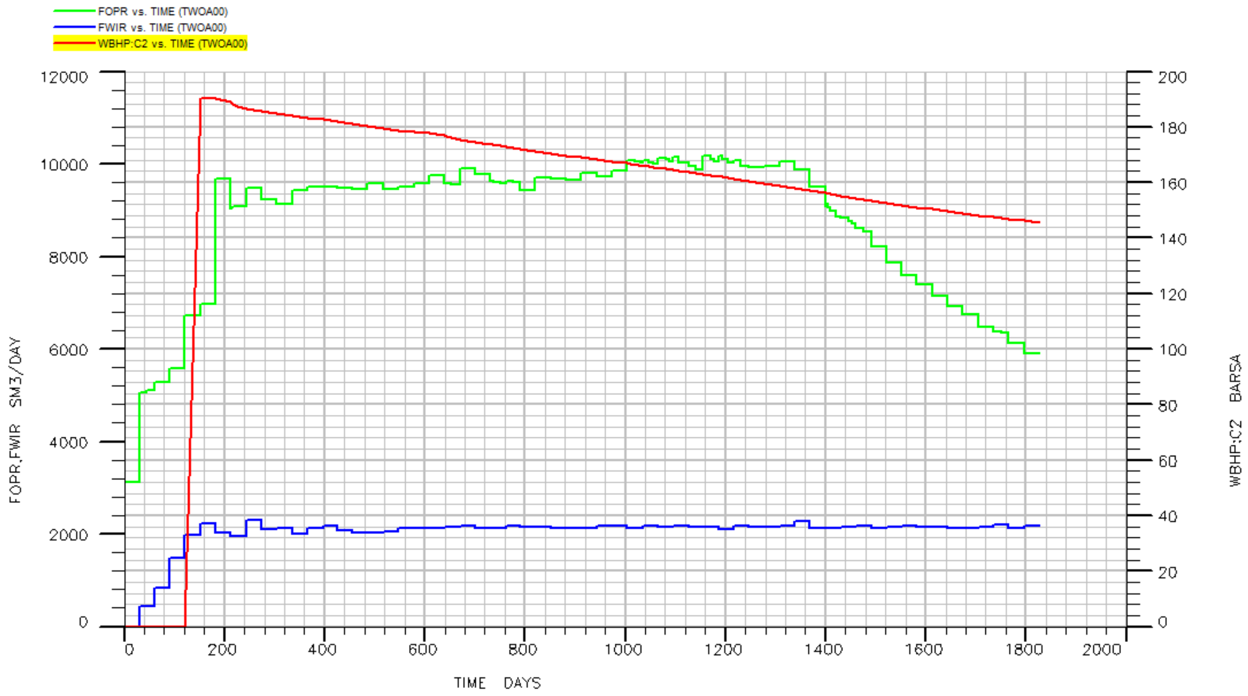


Figure 41 : Oil production vs water injection vs wellbore pressure

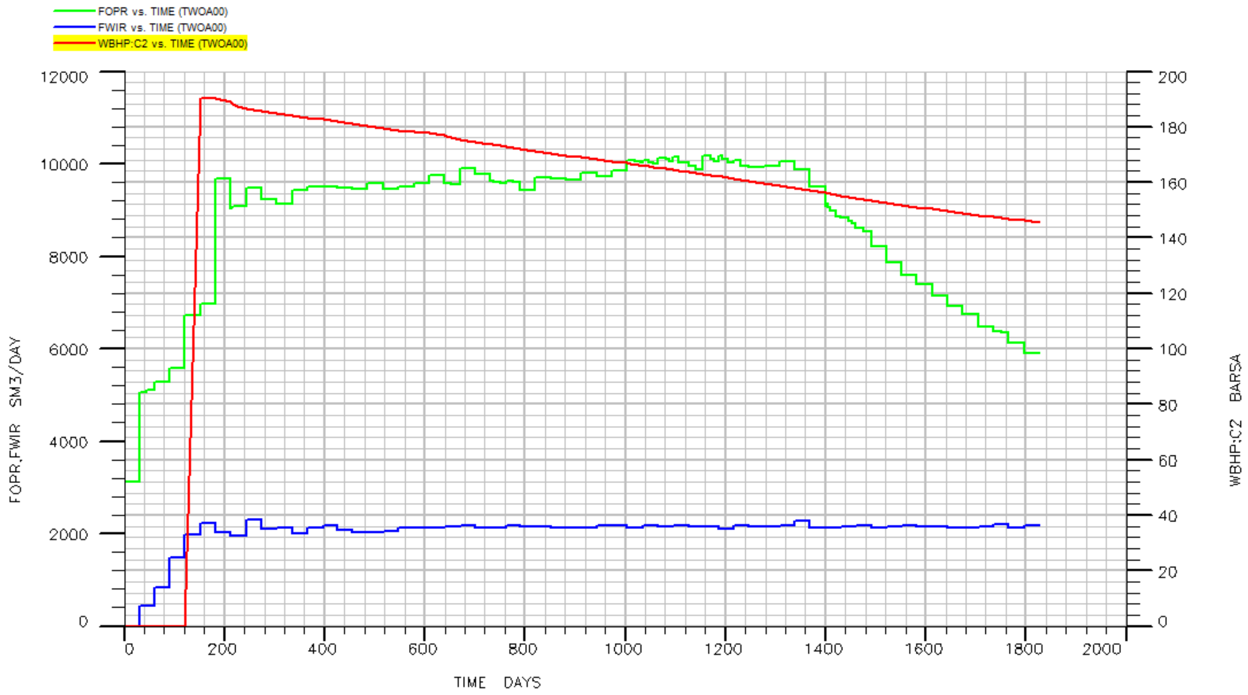


Figure 42 : Oil production vs water injection vs wellbore pressure (after injection)

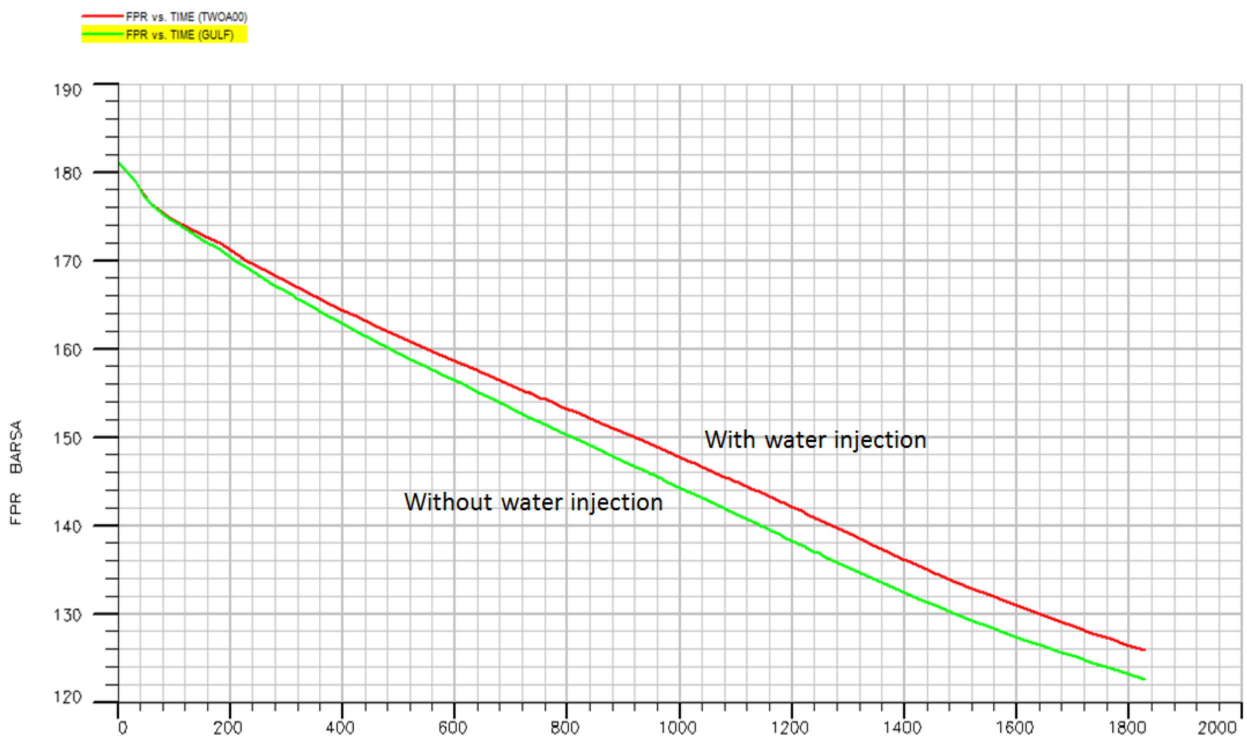


Figure 43 : Water injector well pressure

4.3 DISCUSSION

Rock mechanical properties	Value	Observations	
		Before water injection	After water injection
Young's modulus	340 bar	Stress : -24.43 Strain : -0.0221	Stress : -1554.45 Strain : 5.8282
	690 bar	Stress : -24.43 Strain : -0.0109	Stress : -2159.55 Strain : 4.0119
Poisson's ratio	0.2	Stress : -22.62 Strain : -0.0202	Stress : -2161.78 Strain : 5.6844
	0.3	Stress : -24.43 Strain : -1.010550E-15	Stress : -1865.20 Strain : -0.0167
	0.4	Stress : -26.83 Strain : -0.0105	Stress : -1279.52 Strain : 3.8869

Table 3: One dimensional results

The above table is the result for one dimensional wellbore approach for the water injector well. From the first result in Young's modulus alteration, the values used in the simulation are set to 340 bar and 690 bar. The original value in the data file is 1000 bar. Alteration of the value is to perform a study case to investigate the effect of different Young's modulus value to the stress and strain effects around the wellbore. As the results show, as the Young's modulus increase, stress distribution will decrease after water injection took place. On the other parameter, strain distribution will increase after simulation is done. The results justify the theory of Young's modulus where it is the ratio of normal stress to strain the same axis. Poisson's ratio is the ratio of lateral strain to axial strain. The values are for investigation is set to 0.2, .0.3 and 0.4. The distinct criteria from the result is same as before, where stress distribution decrease after water injection took place and strain distribution increase after the water injection.

Fluids such as water, oil and gas can exist in the pore spaces with the less dese fluids such as gas. The fluids tend to rise upwards through the pore spaces and the denser liquids tending to drain downwards. Although a certain amount of water, oil and gas may remain trapped throughout the rock due to capillary effects. If pore pressure at a depth is equivalent to the pressure at the base of a column of the same pore fluids through the rock, the rock is referred to as being normally pressure and if it is greater, the rock is said to be over-pressured. When water injection took place, the pore fluids will be pressurized and displaced.

In summary, if the stress is positive value, it means the rock undergoes compaction and results in negative strain while if the stress is negative value, it means the rock undergoes expansion and results in positive strain.

Parameter	Observation	
	Before injection	After injection
Well injector pressure	174.9	162.9
Plastic shear strain	0.03	0.04
Plastic displacement	629.05	120.75

Table 4 : Three dimensional results

The above table is the result for three dimensional reservoir approach for the water injector well. There are three parameter investigated in this project to study its changes after water is injected. Well injector pressure is decrease after water injection due to new pressure or additional introduced into the well to displace the original fluid near the wellbore. Plastic shear strain value increase by 0.01 and plastic displacement decreased after water is injected.

Alteration of minimum horizontal stress for initial condition results in 4kPa. After water injection, the pressure decrease to 1.2kPa. As the water injected into the well, the horizontal stress acted upon the wellbore decrease and result in decreasing the pressure in the wellbore as time goes by. The stress model shows that the principal stress is 1701.29Pa.

Young's Modulus or also knows as elastic modulus is a measure of the stiffness of an elastic material. It is defined as the ratio of the stress along an axis over the strain along that axis in the range of stress. Note that Young's Modulus value for sandstone is range from 39Mpa to 69Mpa. High Young's Modulus indicates less stress and strain distribution around well and vice versa. The value of Young's Modulus is taken from the same Terzaghi data file.

In stress distribution model, result shows that as water injected into wellbore, the stress distribution decrease. Terzaghi's principle states that when a rock is subjected to a stress, it is opposed by the fluid pressure of pores in the rock. The results explain the phenomenon of changes in pressure before and after water injection. For strain distribution model, at 690bar the result shows that declining in strain as well as in the 340bar section.

The water injector pressure decrease is due to the presence of big aquifer in the reservoir. This is proved in the simulation run and results in Figure 43. Even without water injection, the pressure decline is more than the pressure decline with water injection. One of the reasons why water is injected is to maintain the reservoir pressure so that the lifetime of the reservoir can be prolonged and to have an optimum production rate. This statement is supported by results in Figure 41 and 42 which show the oil production versus water injection versus wellbore pressure with and without water injection. As for plastic shear strain, the value is decreased after water injection because of the pore spaces expand or increase as pressure is applied through the spaces due to water injection. In case of plastic displacement, the parameter of interest is the displacement in z-direction. A decrease value in z-direction in plastic displacement means compaction drive took place after water injection which is good for the reservoir in term of hydrocarbon production.

CHAPTER 5

CONCLUSION

5.0 CONCLUSION AND RECOMMENDATION

It is undeniable that geomechanics study is very important to aid hydrocarbon production. It gives a better understanding of reservoir condition, prediction of fractures, geometry of rocks, effect of fault presence and many more. There are many things to consider or study in geomechanics because it is a very broad field. Thus, for this project, the author limits the study to one type of EOR, which is water injection well. Parameters like Young's modulus and Poisson's ratio is investigated to study its effects on the injector well. From the study, it is concluded that after water injection took place, the fluid will replace the original water in the reservoir and reduced the original stress. The strain increase in all cases as water is injected. Positive changes stress means rock compaction and results in negative strain while negative changes stress means rock expansion which results in positive strain.

For three dimensional considerations, parameters such as wellbore pressure, plastic shear strain and plastic displacement is studied to determine formation fracture pressure. It is crucial to determine the fracture formation pressure so that the injection rate not exceed pore pressure gradient. Overburden pressure is set fixed so that calculation of effective stress and fracture pressure is possible.

The parameters mentioned are some of the significant attributes in determining the optimum injection rate in well injector and optimum production rate. Geomechanics study is very significant and play vital role in oil and gas industry in term of injection or production. Other than that, by determining the best injection rate and pressure, the operators can save a lot of money and improve the ultimate recovery of oil.

The author recommends to anybody who wants to continue this study to do research on other important parameters in geomechanics so that a better understanding about reservoir can be achieved. The parameters that the author would suggest for future work are Mohr’s circle and Biot’s coefficient. The Biot’s coefficient is strong function of stress changes and Mohr’s circle can defines the maximum limit of shear stress for any normal stress. Fakcharoenphol in his study found that Mohr’s circle can determine failure envelope and creating new micro-fractures which can improve the permeability of a reservoir.

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