EFFECT OF LITHOLOGY BARRIERS AND COMPOSITE LAYERING ON FRACTURE HEIGHT IN UNCONVENTIONAL RESERVOIRS

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---*ABSTRACT*--

Before designing and creating a hydraulic fracture, it is important to understand the parameters that determine the fracture geometry and whether the fracture extends beyond the pay zone. By fixing other mechanical parameters (i.e. Stress, Young's modulus, Poisson's ratio, and Fracture toughness), this study investigates how the lithology barriers and, more importantly, the Composite Layering Effect (CLE) of the pay zone affect the fracture geometry. Additionally, the effect of permeability on fractur geometry at several CLE values examined using three different scenarios (no permeability, low permeability, and high permeability). This study used FracPro software to investigate the effect of lithology barriers and composite layering on the fracture geometry. Several simulation cases were run with different CLEs (1, 10, 20, and 100), and the height/length ratio of the fracture was estimated. A generalized equation was developed that calculates the CLE from the height/length ratio of the fracture in the required range at the payzone. This equation was able to reliably assess containment, showing that it can be used in the fracture treatment of high-risk zones, such as those with water-bearing layers and/or oil-water or oil-gas contact.

Keywords: hydraulic fracture, fracture geometry, Composite Layering Effect, height/length ratio.

I. INTRODUCTION

Hydraulic fracturing is a technology that has been in practice since the late 1940s to improve production from reservoirs. Hydraulic fractures are manufactured flow paths by which hydrocarbons are efficiently extracted from low-permeability rocks. The fracture is constructed by a planned injection of high-pressure fluid that encounters a sufficient volume of rock to result in economic production. When designing a hydraulic fracture project, many parameters must be considered to get a successful hydraulic fracturing job. Composite Layering Effect (CLE) plays a major role in the fracture geometry and design process and it is essential to understand the CLE effect because it controls and affects the fracture height across the layers.

1.1 Composite layering effect mechanism

L. Weijers, et al., (2005) explained the Composite Layering Effect (CLE) mechanism during hydraulic fracturing. CLE reflects the resistance of the fracture growth through layer interfaces. As a fracture tip grows through layer interfaces, some of these interfaces may become partially debonded and the fracture may start growing again at a local weakness offset from the original path. The consequence of composite layering is loss of leverage along the fracture height, resulting in a significant decrease in the vertical growth rate. The model impact of this parameter in the model is that the fracture height is exchanged for fracture half-length**. Figure 1** depicts the CLE effect on fracture height growth. Determination of this value of CLE helps in the model calibration and matching net pressures where additional height confinement is required other than the conventional mechanisms such as stress contrast, modulus contrast, fracture toughness, and permeability.
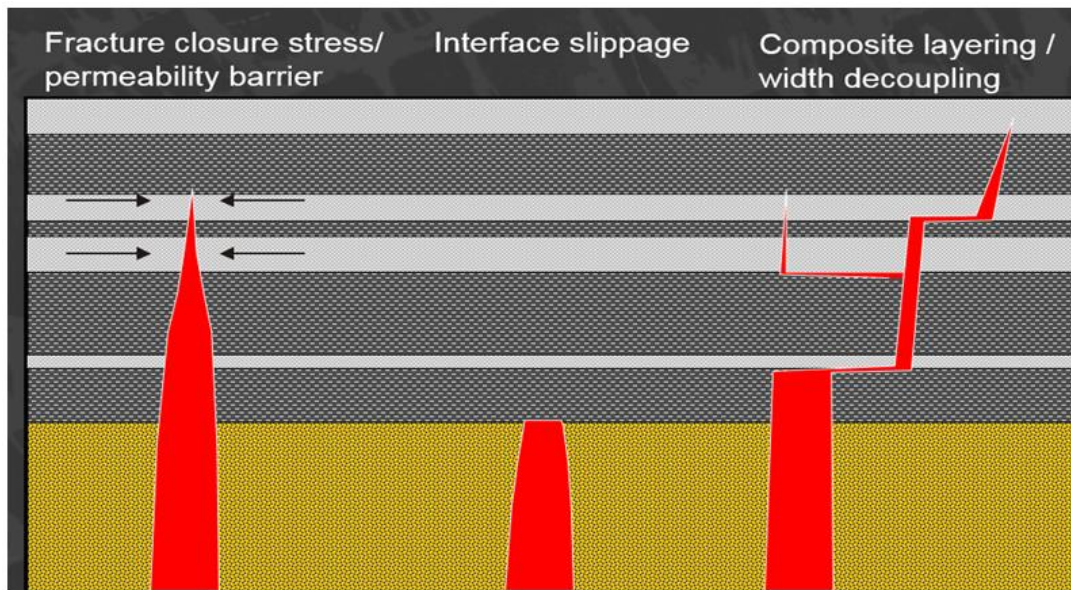
Figure 1: an example of composite layering and width decoupling (Neil, S. 2015).

1.2 Fracture growth in complex media

Many researchers were investigating the fracture growth especially in layered formations (Daneshy, A. A.1978) presented theoretical and experimental developments work involving propagation of hydraulic fractures in layered formations. He did fracturing experiments with layered samples show that with strong bonding between rocks it was difficult to contain a fracture in a formation totally. He concluded that the primary factor in fracturing of layered formations is the strength of the interface. Weak interfaces between the layers are likely to stop fracture propagation, regardless of the relative properties of formations. Strongly bonded interfaces eventually will allow fracture extension through them. (Gordon D. Anderson et al.1981) performed small-scale laboratory experiments to study the growth of hydraulically driven fractures near an unbonded interface in rocks. Their objective was to evaluate under which conditions the hydraulic fractures would cross the interface. They used Nugget sandstone from Utah (3 to 6% porosity) and Indiana limestone (12 to 15% porosity). The results demonstrated that cracks, which intersect the interface from the side opposite the approaching hydraulic fracture, can impede fracture growth across the interface. (C.A. Wright et al. 1999) presented examples of measuring hydraulic fracture growth in different environments; they discussed the implications of the observed fracture growth, for example, factors or mechanisms that control hydraulic fracture growth. They concluded that increased fracture height confinement may result from complicated layer interface effects that are not effectively handled by fracture modeling efforts. (Jennifer L. Miskimins, et al. 2003) presented the results of hydraulic fracture modeling in a hydrocarbon reservoir consisting of laminated sand and shale sequences in Mesaverde reservoir using hydraulic fracture software (GOHFER). In this study, thin beds are considered to be less than 6 inches in thickness. The results of their study strongly indicate that the sand and shale limitations present act as a hydraulic fracture height containment mechanism. The contrast in rock mechanical property values between the sand and shale intervals reduce the fracturing energy available for fracture propagation.

Because fracturing materials (fluids, proppant, chemicals), and pumping hydraulic horsepower are expensive, the industry has been motivated since the inception of fracturing to understand and control fracture growth. Many research were conducted to study the fracture growth in the complex media and the influence of some parameters on fracture growth were investigated too. (Kevin Fisher et al. 2011) presented that hydraulic fracture growth is influenced by a multiplicity of factors that are common in any reservoir. They concluded that in situ stress distribution, interfaces, natural fractures, composite layering and other heterogeneities significantly affect the fracture growth. (X. Garcia et al. 2013) presented a numerical model which incorporates the physics of fracture growth. The approach is based on the discrete element method (DEM) and accounts for the physics of fracture growth from basic principles. They used this approach to study the influence of toughness contrast on the propagation mode of a fracture through an interface separating two formations. Four main propagation modes were observed for Mode I fractures: straight crossing across the interface between layers, arrest at the interface, propagation across the interface but with a T-shaped fracture and reinitiating the fracture with an offset. (Han Li, et al. 2016) utilized a recently developed Finite Element-Discrete Element Method (FEDEM) code to simulate the complex fracture propagation barriers shale formations. They studied hydraulic fracture height predictions in laminated shale formations. The simulation results show that in typical mechanical anisotropic

formation (laminated formation), fracture height is always smaller than the fracture height in mechanical isotropic formation, and the fracture tends to propagate (at least temporarily) along the bedding plane interfaces.

II. METHODOLOGY

2.1. Composite Layering Effect Analysis

In this study, layered formation was built to investigate the effect of composite layering. There were ten layers and the target pay zone was sandstone with the height of 89 ft. **Figure 2** shows all mechanical properties of the layers where all these properties above and below the pay zone were maintained constant. Several simulation cases were run according to the following assumptions:

1. Estimated height to length ratios were varied from 0.1 to 1 for a given CLE payzone value.
2. Regenerate the data for a different payzone CLE value. We chose 1, 10, 20 and 100.
3. Additionally, the effect of permeability was studied for three scenarios; no permeability, low permeability, and high permeability.

Figure 2: layers and input parameters (FracPro software)

Table 1 illustrates the parameters of treatment design have applied as a real data to be used in FracPro software

Table 1: Design Treatment Schedule

Stage #	Stage Type	Elapsed Time min:sec	Fluid Type	Clean Volume (gal)	Prop Conc (ppg)	Stage Prop. (klbs)	Slurry Rate (bpm)	Proppant Type
Wellbore Fluid			KCL_3	7165				
1	Water injection	20:14	WG1812CP	8500	0.00	0.0	10.00	
2	Shut-in	25:14	SHUT-IN	0	0.00	0.0	0.00	
3	Minifrac	34:09	WG1812CP	15000	0.00	0.0	40.00	
4	Shut-in	64:09	SHUT-IN	0	0.00	0.0	0.00	
5	Main frac pad	87:58	SIR27CP	40000	0.00	0.0	40.00	
6	Main frac slurry	94:21	SIR27CP	10000	2.00	20.0	40.00	CarboProp 20/40
7	Main frac slurry	101:35	SIR27CP	11000	3.00	33.0	40.00	CarboProp 20/40
8	Main frac slurry	110:26	SIR27CP	13000	4.00	52.0	40.00	CarboProp 20/40
9	Main frac slurry	120:15	SIR27CP	14000	5.00	70.0	40.00	CarboProp 20/40
10	Main frac slurry	126:45	SIR27CP	9000	6.00	54.0	40.00	CarboProp 20/40
11	Main frac slurry	128:59	SIR27CP	3000	7.00	21.0	40.00	CarboProp 20/40
12	Main frac flush	133:12	WG1822CP	7100	0.00	0.0	40.00	
13	Shut-in	138:12	SHUT-IN	0	0.00	0.0	0.00	

Table 2 shows dept of all layers including the target pay zone and mechanical properties of these layers

Table 2: Layer Parameters

Layer #	Top of zone TVD, (ft)	Top of zone MD, (ft)	Stress (psi)	Stress Gradient (psi/ft)	Young's modulus (psi)	Poisson's ratio	Lakoff Coefficient (ft/min½)	Pore Fluid Perm., (mD)
33	11357.0	11357.0	11478	1.010	2.31e+06	0.310	0.000e+00	0.000e+00
34	11368.0	11368.0	10074	0.886	3.89e+06	0.240	0.000e+00	0.000e+00
35	11376.0	11376.0	11686	1.026	1.75e+06	0.290	0.000e+00	0.000e+00
36	11399.0	11399.0	11686	1.025	1.75e+06	0.290	0.000e+00	0.000e+00
37	11405.0	11405.0	11686	1.025	1.75e+06	0.290	0.000e+00	0.000e+00
38	11407.0	11407.0	11686	1.024	1.75e+06	0.290	0.000e+00	0.000e+00
39	11409.0	11409.0	11686	1.023	1.75e+06	0.290	0.000e+00	0.000e+00
40	**11428.0**	**11428.0**	**10177**	**0.887**	**3.32e+06**	**0.250**	**2.178e-03**	**2.100e-02**
41	11517.0	11517.0	11686	1.014	1.75e+06	0.290	0.000e+00	0.000e+00
42	11527.0	11527.0	11686	1.014	1.75e+06	0.290	0.000e+00	0.000e+00
43	11528.0	11528.0	11686	1.013	1.75e+06	0.290	0.000e+00	0.000e+00
44	11538.0	11538.0	11686	1.012	1.75e+06	0.290	0.000e+00	0.000e+00
45	11552.0	11552.0	11975	1.036	2.42e+06	0.310	0.000e+00	0.000e+00
46	11565.0	11565.0	10712	0.926	3.78e+06	0.260	0.000e+00	0.000e+00

2.2. Estimate height length ratio in layer

The first part of this study focused on developing a generalized equation to determine a CLE value for a given layer based on the desired estimated height/length ratio or height confinement in the layer. We discovered the height/length ratio in the layer, as predicted by the software, depends on the reference CLE assigned to the payzone. This equation enables fracture optimization prior to fracture design. **Figure 3** shows a Cartesian plot of the estimated height/length ratio in each layer vs. the composite layering effect value that was assigned to the layer. Four curves were generated based on different pay zone CLE value 1, 10, 20 and 100. Interesting all the curve fits has the same power index of ~ -0.434.

The same plot was regenerated on a log-log scale. **Figure 4** have the same slope, but different intercepts. These intercept values were estimated by plotting them vs. their respective pay zone CLE values forming a linear trend as shown in **figure 5**. The results allowed us to use a generalized model in estimating the height/length ratios in each layer based on CLE assigned to the pay zone and the layer.
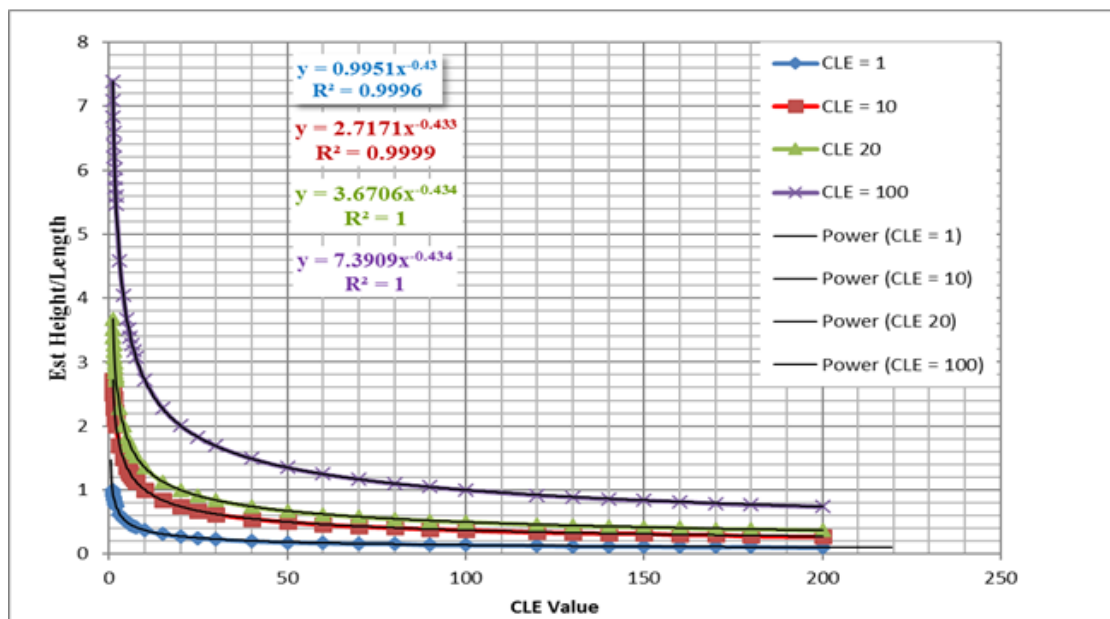

Figure 3: Estimate Height-length ration as function of different CLE value.

Estimated intercept from pay zone CLE value can be computed using the following equation:

$$I = a X^b \qquad (1)$$

Where:

I: Intercept for a given pay zone CLE value

X: Given CLE payzone value

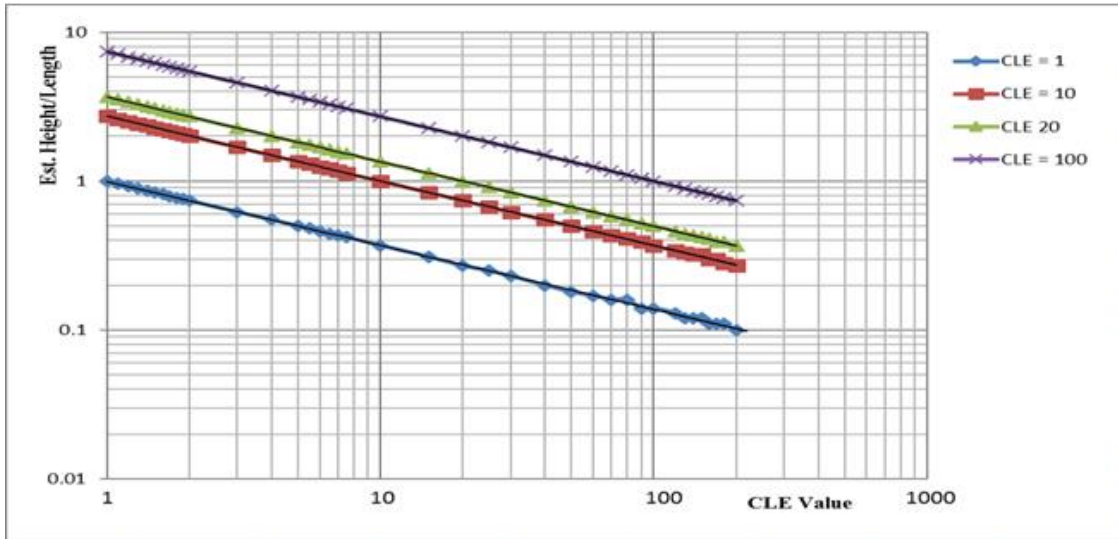 a: 0.9978 (constant)

 b: 0.4349

Figure 4: Estimate Height-length ration as a function of different CLE value on the log-log plot.

This intercept is used to calculate the height/length ratio in the layer from the following equation:

$$Y = I Z^{-b} \qquad (2)$$

Where:

Y: Estimated height/length for the layer

Z: CLE assigned to the layer

Figure 5: The intercept value for all CLE value from 1 to 100

2.3. Critical Point

The modeled half-length **figure 12** is seen to decrease with increasing height/length ratios in the layers. As discussed previously, an increase in height/length ratio indicates lower composite layering effect in the layer which means lower height confinement and more rounded fracture geometry. However, we observed a critical point (height/length ratio in the layer) after the final predicted half-length increases. This critical point shifts to the right with increasing payzone CLE value. Furthermore, as shown in **figure 12**, the modeled height is seen to increase with increasing height/length ratios in the layers. An increase in height/length ratio indicates lower composite layering effect in the layer which means lower height confinement. The same critical point was observed when the height decreases slightly.
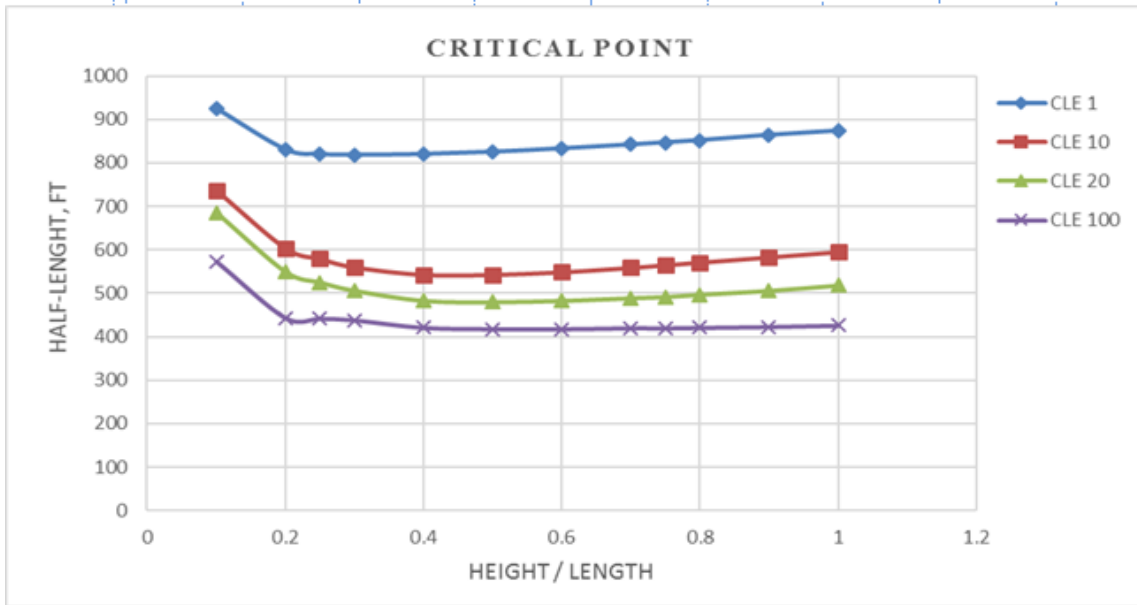

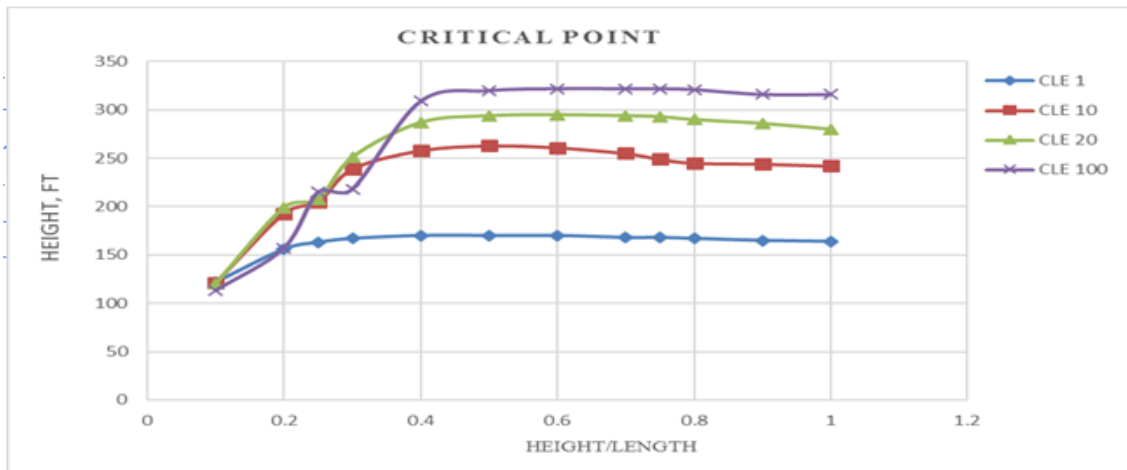**Figure 6: Half Length of the critical point for different CLE values**

Figure 7: Height of the critical point for different CLE values

The average width decreases with increase in estimated height to length ratios in the layers or decreasing height confinement. A lower composite layering effect in the layers results in lower interface slip effects allowing fracture width profile to be distributed more evenly across layer. Conversely, as interface slip increases we observed a greater width in the payzone and narrower fracture width in the layers above and below. This effect is described in the following plot as shown in **figure 13**. It is seen to be more pronounced and fracture width profile is increasingly uneven as the CLE is increased in the payzone.
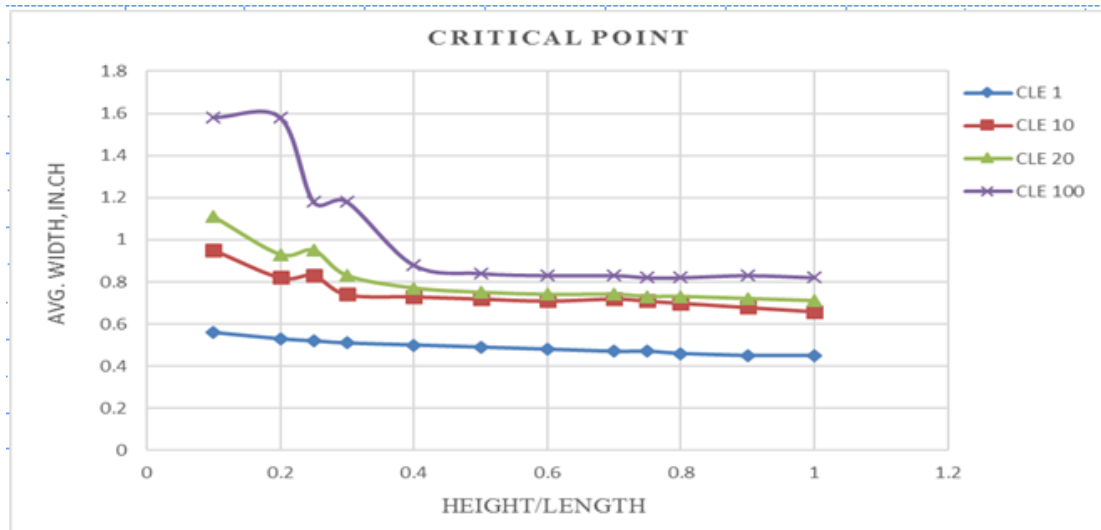
Figure 8: Average width of the critical point for different CLE values.

2.4. Effect of permeability

The same graphs were analyzed for the effect of permeability and the compare between CLE value of 1 and 100 in the payzone.

Lower fracture half-length was observed in a high permeability formation as shown in **figures 9 and 10** . Also, the rate of decrease in fracture half-length with increase in height/length ratios for high permeability formation was greater. This phenomenon is attributed to the high leak off fluid pressure as well as the lower fracture fluid pressure in high permeability formation. Furthermore, Low and no permeability cases showed similar results, which might be due to low magnitude of low permeability parameters that was chosen.

Moreover, a comparison was made between high and low payzone CLE. The results show that, increasing pay zone CLE values caused a reduction in the fracture half-length scales. Whereas, in low CLE in payzone, the average variation in the fracture width exhibited lower values compared to payzone with high CLE **Figures 11 and 12**. The effect of permeability were observed with high leak-off in high permeability zone, which resulted in lower fracture width. This effect was observed in the payzone that exhibit high CLE, only after the effects of height confinement was reduced to height/length ratios of 0.6.

Figures 13 and 14 shows an increase in fracture height with payzone CLE . Moreover, when we have a low CLE values , we will have a lower chance to have interface slip effect. This resulte indicated that higher payzone CLE causes higher chance for a unconfinment fracture design. Furthermore, the low permeability will help the study to design fracture geometry in a better desirable range of fracture high in a payzone.
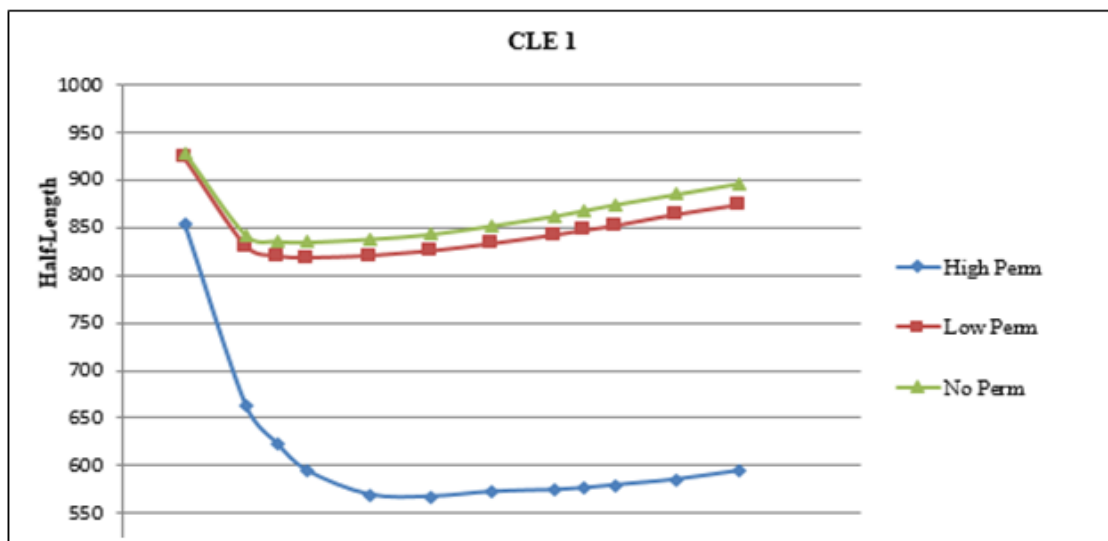

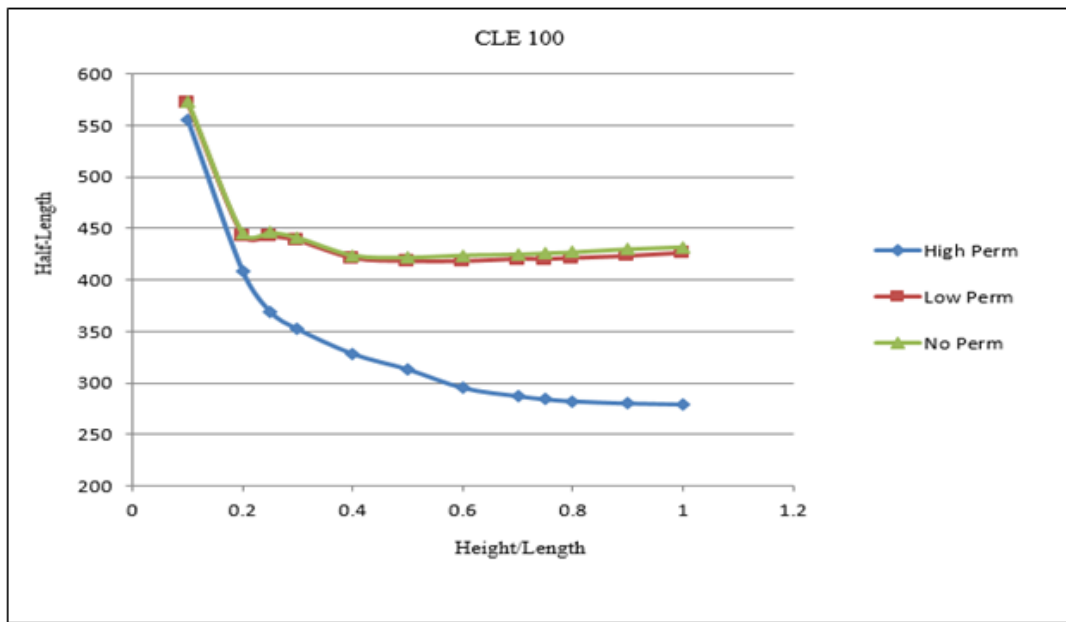**Figure 9: Half Length comparison for different permeability zone (payzone CLE = 1)**

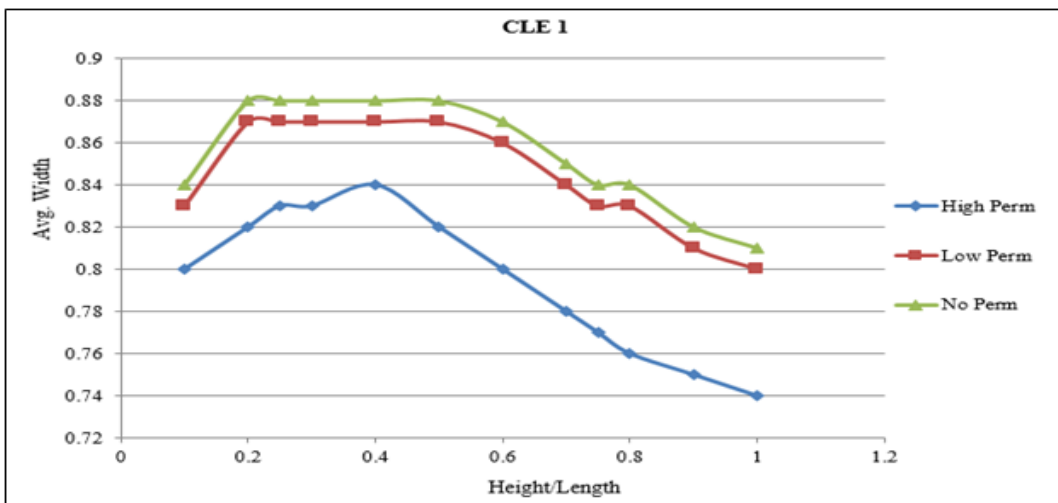**Figure 10: Half Length comparison for different permeability zone (payzone CLE = 100)**

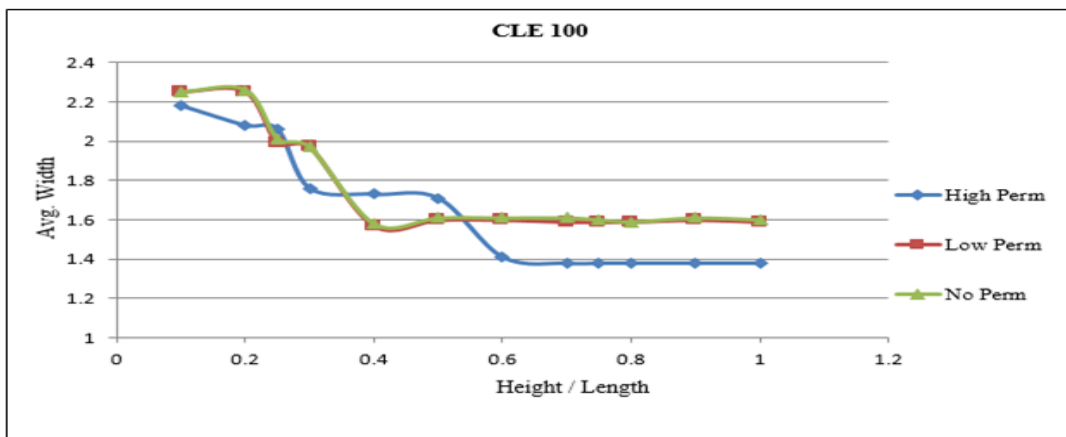**Figure 21: Avg. Width comparison for different permeability zone (payzone CLE = 1)**

Figure 3: Avg. width comparison for barrierent permeability zone (payzone CLE = 100)
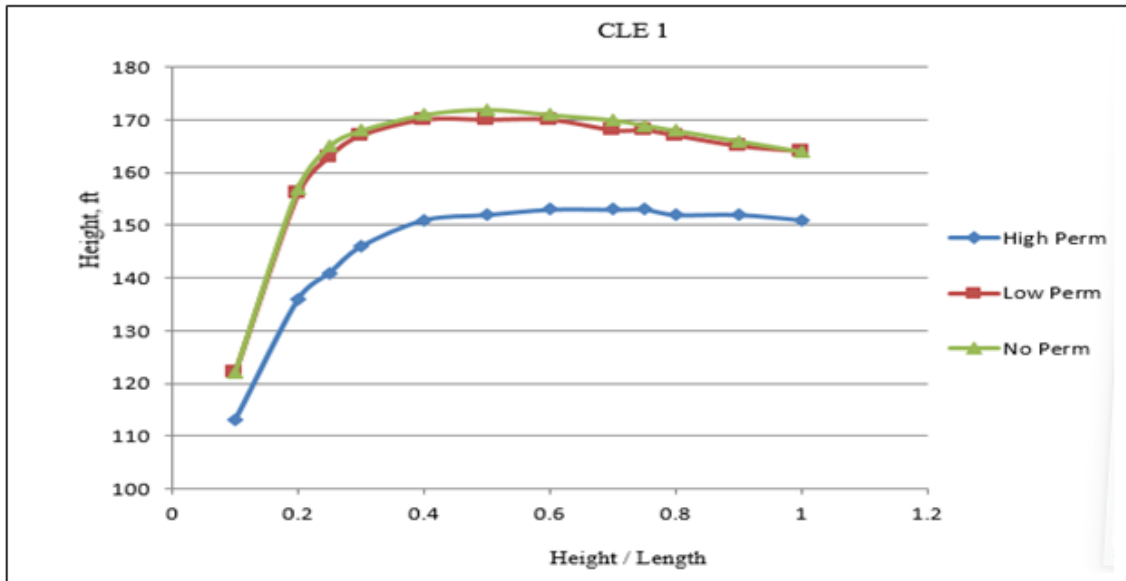
Figure 13: Fracture height comparison for different permeability zone (left - payzone CLE = 1)
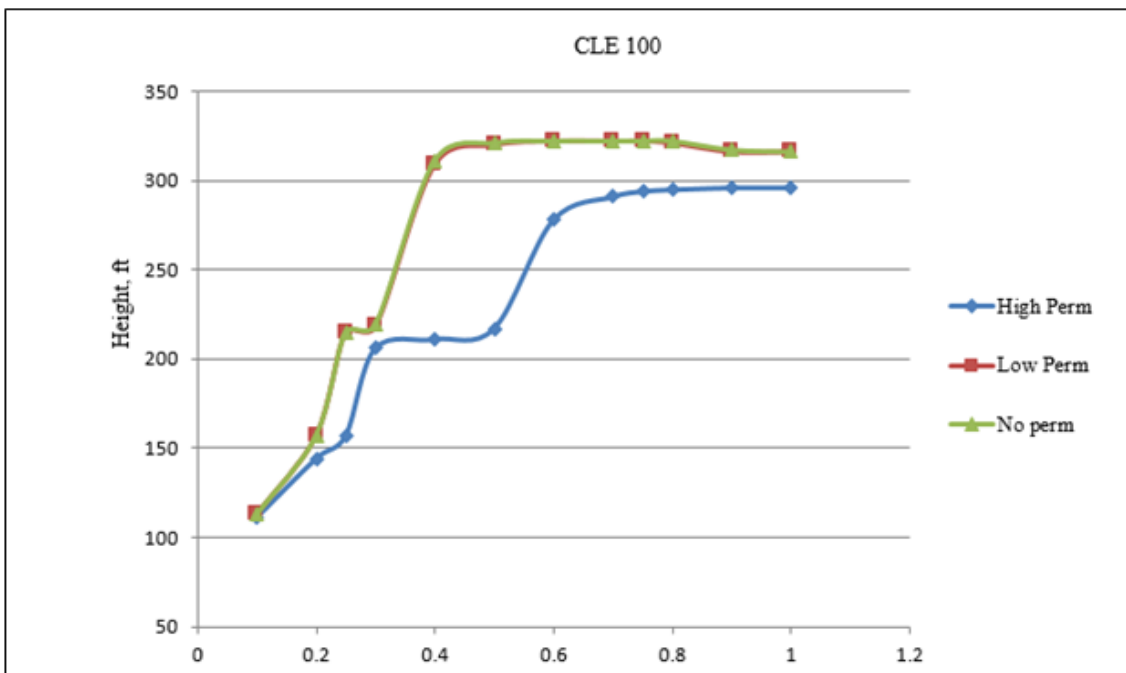

Figure 14: Fracture Height comparison for different permeability zone (payzone CLE = 100)

Figures 15 and 16 present the effect of pay zone permeability on the fracture width and height at the same composite layering effect (CLE =1). At 0.2 md, the fracture height is 145 feet which expanded out of the pay zone boundaries, and the maximum fracture width is 0.8 inches, whereas at 0.0002 md, the fracture height is 160 feet, and the maximum fracture width is 0.9 inches.
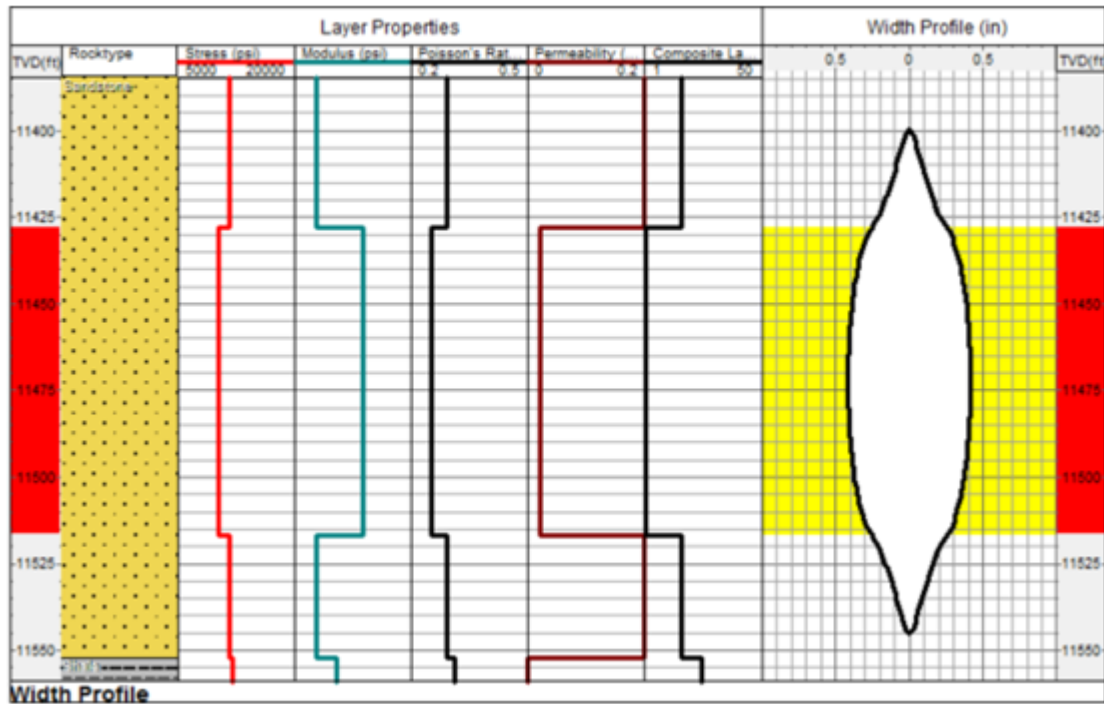
Figure 15: Width and height profile of the fracture at CLE = 1 and pay zone permeability is 0.2 md. (FracPro software)
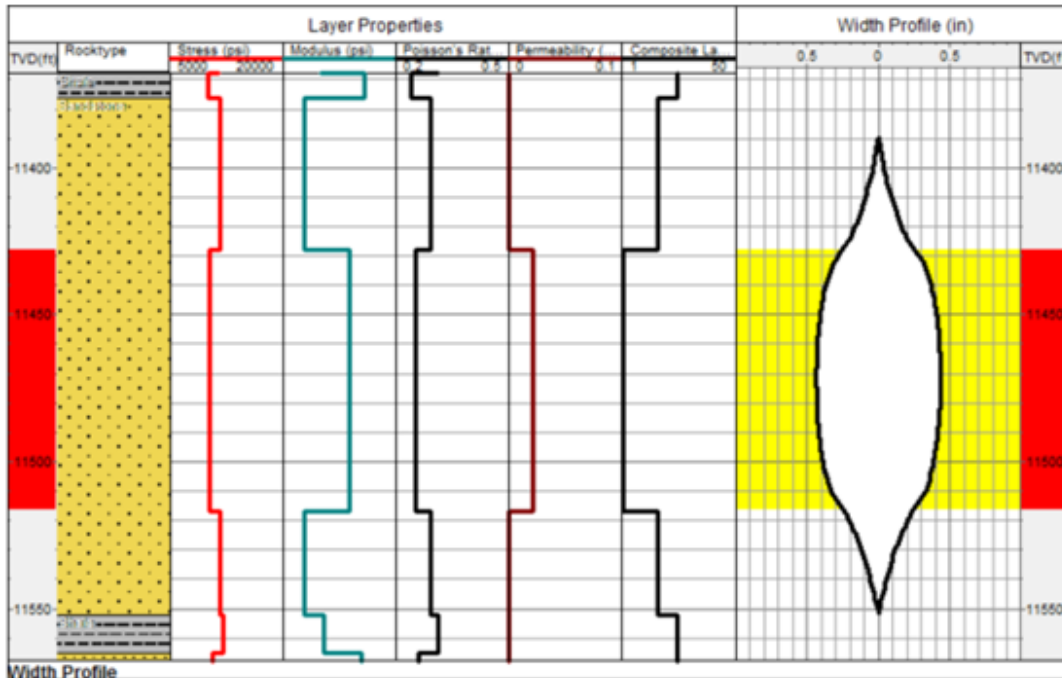

Figure 16: Width and height profile of the fracture at CLE = 1 and pay zone permeability is 0.0002 md. (FracPro software)

Figures 17 and 18 present the effect of payzone permeability on the fracture width and height at the same composite layering effect (CLE=100). At 0.2 md, the fracture height is 195 feet and the maximum fracture width is 1.7 inches, whereas, at 0.0002 md, the fracture height is 205 feet and the maximum fracture width is 1.9 inches.
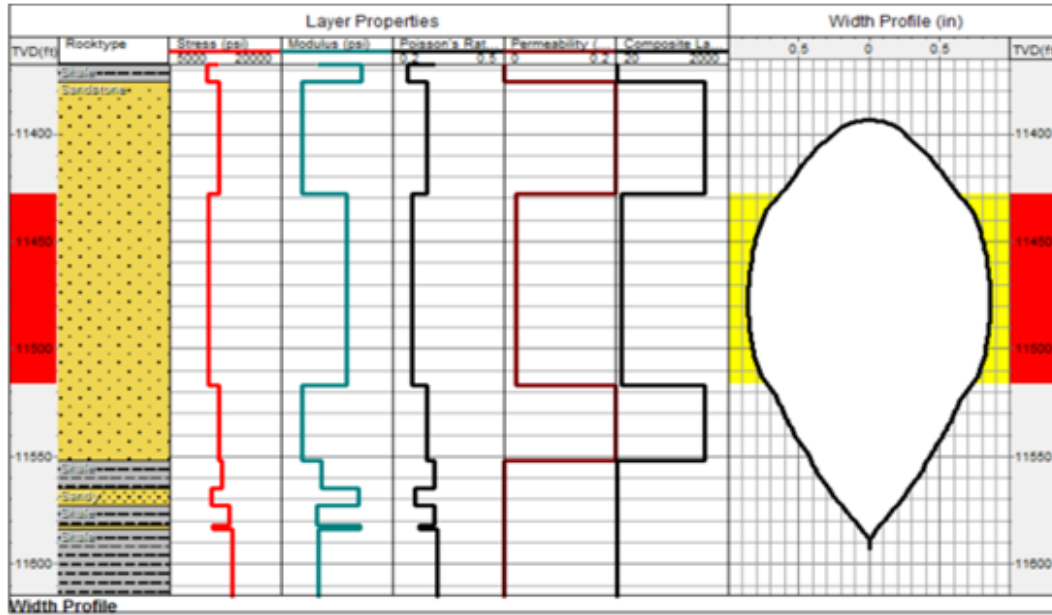
**Figure 17: Width and height profile of the fracture at CLE = 100 and pay zone permeability is 0.2 md.
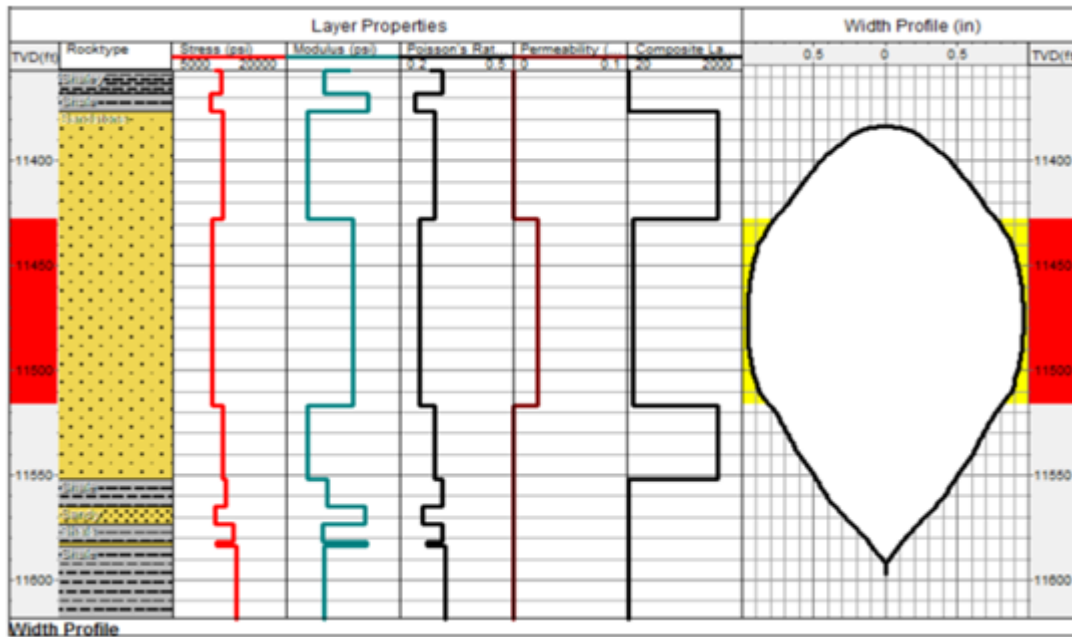(FracPro software)**

**Figure 18: Width and height profile of the fracture at CLE = 100 and pay zone permeability is 0.0002 md.
(FracPro software)**

III. CONCLUSION

FracPro software was utilized to analyze the composite layering effect (CLE) on the fracture height and width with different permeability values. Based on the study presented in this paper there are three parameters change for different payzone CLE at a specific point which is the critical point with permeability effect as following:

- At the Half-Length dimension; the results showed that the critical point is high and this point decreases as CLE is increased, also the critical point shifted to the right with increasing CLE. As well the permeability has an obvious effect here where it decreases with decreasing CLE, also decreasing CLE tends to have more of confined fracture, whereas at the low permeability formation tends to be confined fracture.

- At the Height dimension; the critical point increases with increasing CLE, and lower CLE provides a chance to have confined fracture. Low permeability gives a higher chance to have unconfined fracture.

- At the Average-Width dimension the critical point decreases with increasing CLE, and lower CLE gives a chance to have lower interface slip effect. The permeability increases with increasing CLE, and high CLE chances to have a higher chance unconfined fracture, whereas the low permeability tends to have confined fracture.

- Further work is needed, especially mineralogical and chemical composition investigation as well as X- ray computed tomography study, to corroborate the conclusion obtained from the equation presented herein.

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