

Integrity Insitu has developed and successfully applied a new approach to obtain Closure Pressure magnitude without injecting fluid into a formation

Anna Iuferova, Marisela Sanchez, Cory Fehr, Integrity Insitu, Canada

Introduction

Understanding minimum horizontal stress (S_{hmin}), both its magnitude and orientation, is of paramount importance in the Oil and Gas sector. Accurate measurement of these parameters can help to enhance wellbore stability and ensure that drilling operations are safe and cost-efficient. This data can also be used to optimize hydraulic fracturing, to design and propagate fractures in the targeted layer, improve well casing design, predict well casing collapse, sand production and fault reactivation. All of these potential problems, if they occur, result in increased non-productive time (NPT) and expense. Precise S_{hmin} estimation is crucial for ensuring operational safety, maximizing hydrocarbon recovery, and improving the economic reliability of oil and gas projects.

In the Oil and Gas Industry, various tests are commonly used to measure closure pressure magnitude (such as XLOT, DFIT, Mini-Frac, etc.). It is very important to mention that all these methods rely on the fundamental principle of injecting fluid into the rock formation to create and propagate a fracture and are suitable for testing different types of rock with depths ranging from 300m to 3000m+. However, they are always perceived to be very expensive in terms of time and operational costs and are also limited by fluid compatibility challenges, proximity to faults, and the interference caused by fractured reservoirs.

In Civil Engineering, Pressuremeter tools have been used to measure minimum horizontal stress since 1955. Closure pressure is a key parameter for assessing the stability of such underground structures as tunnels, shafts, and deep foundations. Pressuremeters are commonly applied in clays, sands, and weak to moderately strong rocks with depths ranging from a few meters up to a few hundred meters. It's important to note that the testing procedure does not require the injection of fluid into a formation and instead involves inserting a cylindrical probe into a borehole which expands by applying fluid/gas pressure to the inside of the probe.

This article examines a comparison of S_{hmin} measurements obtained using the classical Mini-Frac test approach and

those obtained with the Intelligent Packer technology developed by Integrity Insitu (Calgary, Canada) on matching concrete test bodies.

Intelligent Packer measurements

The Insight Tool contains multiple functionalities: gamma sonde, directional/navigation package, Shearhead and Intelligent Packer. The Intelligent Packer (IP), as shown in Figure 1, is an advanced, ruggedized version of a pre-bored Pressuremeter. It is designed to measure the magnitude and orientation of minimum horizontal stress S_{hmin} , Shear Modulus, Residual Strength, and Limit Pressure with high accuracy in downhole conditions. The Insight Tool was designed to operate in both vertical and horizontal sections of boreholes in shallow and high-pressure high-temperature (HPHT) deep environments. One of the main advantages of this tool compared to classical approaches to measure closure pressure magnitude is that it is performed without injecting fluid into the formation. Operational depth range varies from several meters up to 13,685 m with hydrostatic pressure of up to 20,000 psi. Operational time ranges from 45 minutes to two hours per zone, depending on test design.



Figure 1. Insight Tool

The test procedure involves inserting a cylindrical probe with an expandable membrane into a borehole, and expanding it by applying fluid/gas pressure inside the probe. When placed at the target depth, the membrane is inflated against the wellbore wall, applying a maximum pressure from within the packer of up to 13,000 psi until the formation starts to deform.

The radial expansion of the packer induces stress in the surrounding soil or rock, with constant measurements of the corresponding pressure and radial deformation being collected and transmitted to surface in real-time. Shmin magnitude can be directly determined by analyzing the stress-strain response, providing critical geomechanical insights.

In addition to the Shmin value, the Intelligent Packer delivers Shear Modulus and stress orientation measurements in real-time, making it a valuable tool for obtaining important calibration points to optimize drilling and/or completion operations, well designs and maximizing hydrocarbon recovery while minimizing costs and risks.

In 2024, Integrity Insitu conducted tests of the Intelligent Packer tool in a concrete body with constant recording of time, pressure and radial displacement of each of 12 measurement arms inside the tool. The test lasted 175 min. Maximum achieved differential pressure was 1,021 psi. Photos of the concrete body before and after the testing are in shown Figure 2 and Figure 3 .



Figure 2 Concrete body before Intelligent Packer testing



Figure 3. Concrete body after Intelligent Packer testing

The testing procedure included ten loading/unloading cycles to achieve multiple accurate and reliable measurements of the formation's stress-strain behaviour, and in particular, its elastic properties and plastic deformation. During Intelligent Packer testing, the following parameters were recorded: pressure, differential pressure, displacement of each of 12

arms, average arm displacement, increase in each of 6 diameters, and many others. Detailed analysis of Pressure vs. Time (Figure 4), Displacement vs. Time (Figure 5) and Pressure vs. Displacement curves (Figure 6) provide important information about the elastic properties and Shmin magnitude/orientation of the formation.

As can be seen in Figure 4, Figure 5 and Figure 6, several loading/unloading cycles were performed with gradually increasing pressure limits (up to Cycle 5) in order to get a better understanding of the formation's mechanical behaviour and to identify elastic and plastic deformation of the concrete body. In Cycle 5, pressure reaches its peak point and the breakdown of the concrete body was measured at a differential pressure of 1021 psi (Figure 4).

After reaching the breakdown point of the formation in Cycle 5, the large increase in arm displacements can be noticed in Cycle 6 (Figure 5), which confirms that the wellbore has indeed failed.

The maximum loading pressure of Cycles 7 to 10 was approximately 60% of the breakdown pressure. It should also be noted that a constant increase in diameter is observed (Figure 5), indicating propagation of the fracture until its final closure after complete unloading of the system after the 10th cycle.

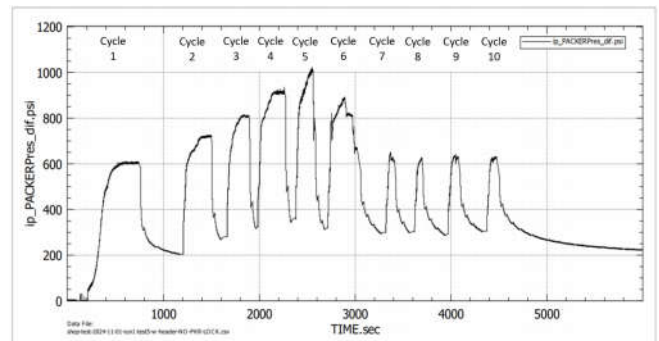


Figure 4. Intelligent Packer test, Pressure vs. Time Plot

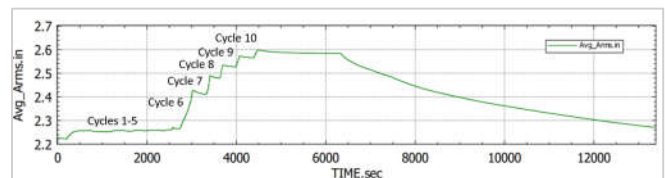


Figure 5. Intelligent Packer test, Displacement (Average arm position) vs. Time Plot

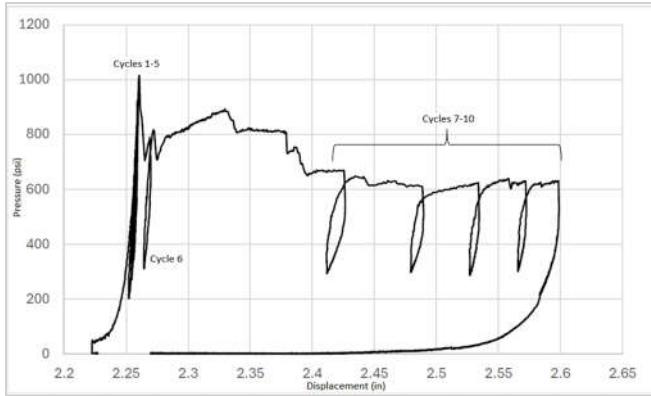


Figure 6. Intelligent Packer test, Pressure vs. Displacement Plot

The closure pressure is determined from the Pressure vs. $(\text{Time})^{1/2}$ plot at the point where the linear trend changes. The Shmin magnitude, estimated from the Intelligent Packer test, is equal to 52 psi (Figure 7).

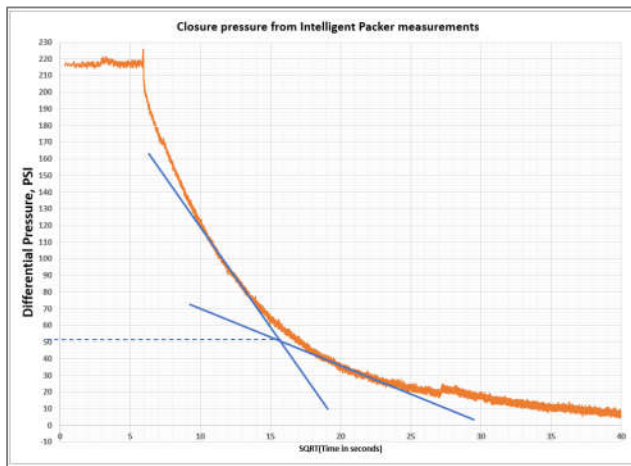


Figure 7. Shmin determination from Intelligent Packer test

Mini-Frac test measurements

A Mini-Frac test is a small-scale hydraulic fracturing operation conducted to evaluate key geomechanical properties of the reservoir such as minimum horizontal stress (Shmin) and others. These properties are very important for calibrating geomechanical models for drilling and hydraulic fracturing purposes.

Mini-frac testing procedures involve an injection of a small volume of fluid into a formation at a controlled rate in order to initiate and propagate a fracture. Then, when the injection stops, the pressure decline is monitored to determine fracture closure pressure and fluid leak-off behavior.

A schematic pressure-time plot illustrating mini-frac behaviour is shown in Figure 8. In the schematic example the pumping rate is constant, so that pressure increases linearly with time as the volume of the wellbore is fixed. The peak pressure is called FBP (Formation Breakdown Pressure) and represents the pressure at which the formation fractures. If pumping continues at a constant rate, the pumping pressure will drop after FBP to a relatively constant value which is called FPP (Fracture Propagation Pressure). This is the pressure associated with propagation of the fracture away from the well. FCP (Fracture Closure Pressure) is determined by plotting Pressure as a function of $(\text{Time})^{1/2}$ and detecting a change in linearity of the pressure decay.

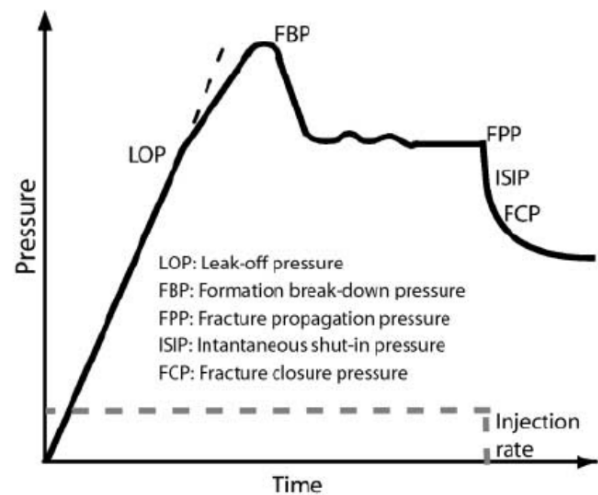


Figure 8. Typical Pressure vs. Time curve obtained from Mini-Frac testing

In 2024, Integrity Insitu (Calgary, Canada) performed a Mini-Frac test inside a concrete body which was built to match that used for Intelligent Packer testing. Figure 9 and Figure 10 display photos of the concrete body before and after the hydraulic fracture occurred. Figure 10 clearly shows hydraulic fluid gushing out of the concrete body, which is additional evidence of the creation of a crack.



Figure 9. Concrete body before Mini-Frac test



Figure 10. Concrete body after Mini-Frac test

The Pressure-Time curve recorded during the Mini-Frac test inside the concrete body is shown in the Figure 11. Testing included 5 injection/falloff cycles. Breakdown Pressure was reached during the first cycle and was equal to 626 psi. After reaching the peak pressure, the injection pressure dropped to approximately 150 psi at which point the fracture started to propagate. During each of cycles 2 to 5, the maximum pressure increased to approximately 140 psi.

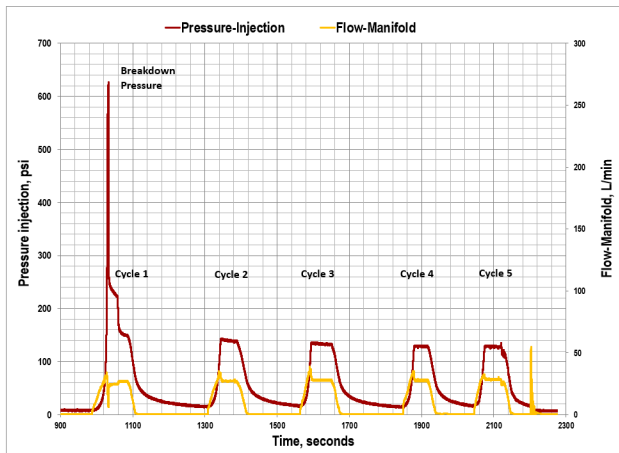


Figure 11. Mini-Frac test. Pressure vs. Time plot

Closure pressure was determined based on the Pressure vs. $(\text{Time})^{1/2}$ plot by identifying the point where the slope of the pressure decline changes (Figure 12). At first, the pressure decreases in a non-linear manner due to fracture storage effects, then transitions into a linear decline as the fracture begins to close. The closure pressure is identified at the point where this linear trend shifts. Closure pressure magnitude (Shmin), estimated from the Mini-Frac test, is equal to 51-52 psi.

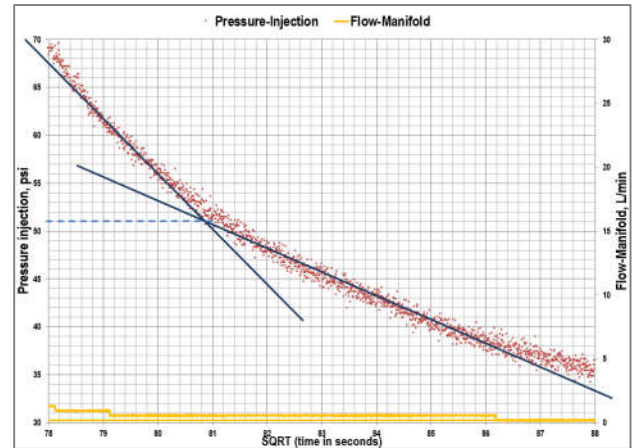


Figure 12. Shmin determination from Mini-Frac test

Conclusion

In conclusion, the comparison between Intelligent Packer Shmin magnitude and Mini-Frac testing Shmin magnitude has shown that both methods provided very similar results when they were applied to identical concrete bodies. The data shows that the Shmin value obtained from the Intelligent Packer test closely matches that obtained by the Mini-Frac test, indicating that Intelligent Packer testing is an accurate and reliable method for estimating minimum horizontal stress (Shmin).

Although both methods provide similar results in estimating closure pressure (Intelligent Packer Shmin magnitude estimation = 52 psi, Mini-Frac Shmin magnitude estimation = 51-52 psi), one of the main advantages of the Intelligent Packer test is its time-efficiency (45 minutes - two hours depending on test design) and cost-efficiency. Mini-Frac testing requires the injection of fluid into the formation to create and propagate a fracture and then wait for that fluid to return to the wellbore, while Intelligent Packer tests do not involve any fluid injection, making it a faster and less expensive option. The Intelligent Packer also eliminates risks associated with fluid compatibility challenges, proximity to faulting, and complications introduced to the analysis of results when working in fractured reservoirs. These differentiators make the Intelligent Packer an excellent choice for estimating Shmin magnitude and stress orientation, improving time and cost-efficiency of any Oil and Gas project.