Advancing Reservoir Performance

iPerf SHOCK^{SM}

Lessons Learned, Deep Water West Africa

BAKER HUGHES

Introduction

- PulsFrac Overview
- Modeling Approach
- Results
- Conclusion/Limitations

Pulsfrac Overview

- Physics-based, finite difference modeling software package that simulates dynamic downhole events and reservoir activity during the perforation event
- Field tested and optimized over a 15 year period
- Verified using high speed gauges

Shock Modeling Characteristics

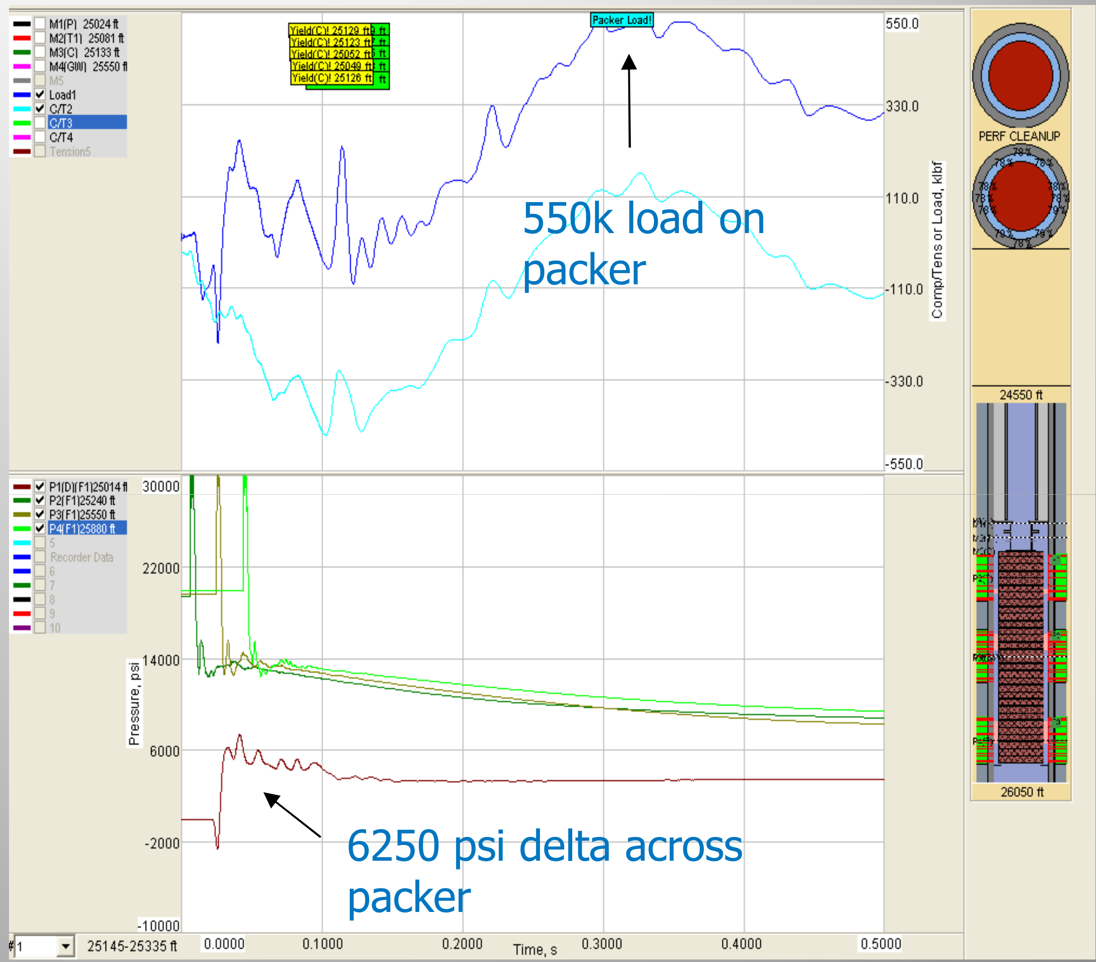
- Mechanical forces acting on the bottom hole assembly
  - Collapse
  - Burst
  - Buckle
- Pressure surges
  - Inside the tubulars
  - Outside the tubulars
  - Acting on the packer
  - Intentional or unintentional dynamic underbalance conditions
- Applications
  - Load analysis on packers, bridge plugs, tubulars
  - Pressure surge/spike analysis on downhole tools
  - Pre-job design tool for risk mitigation

Value

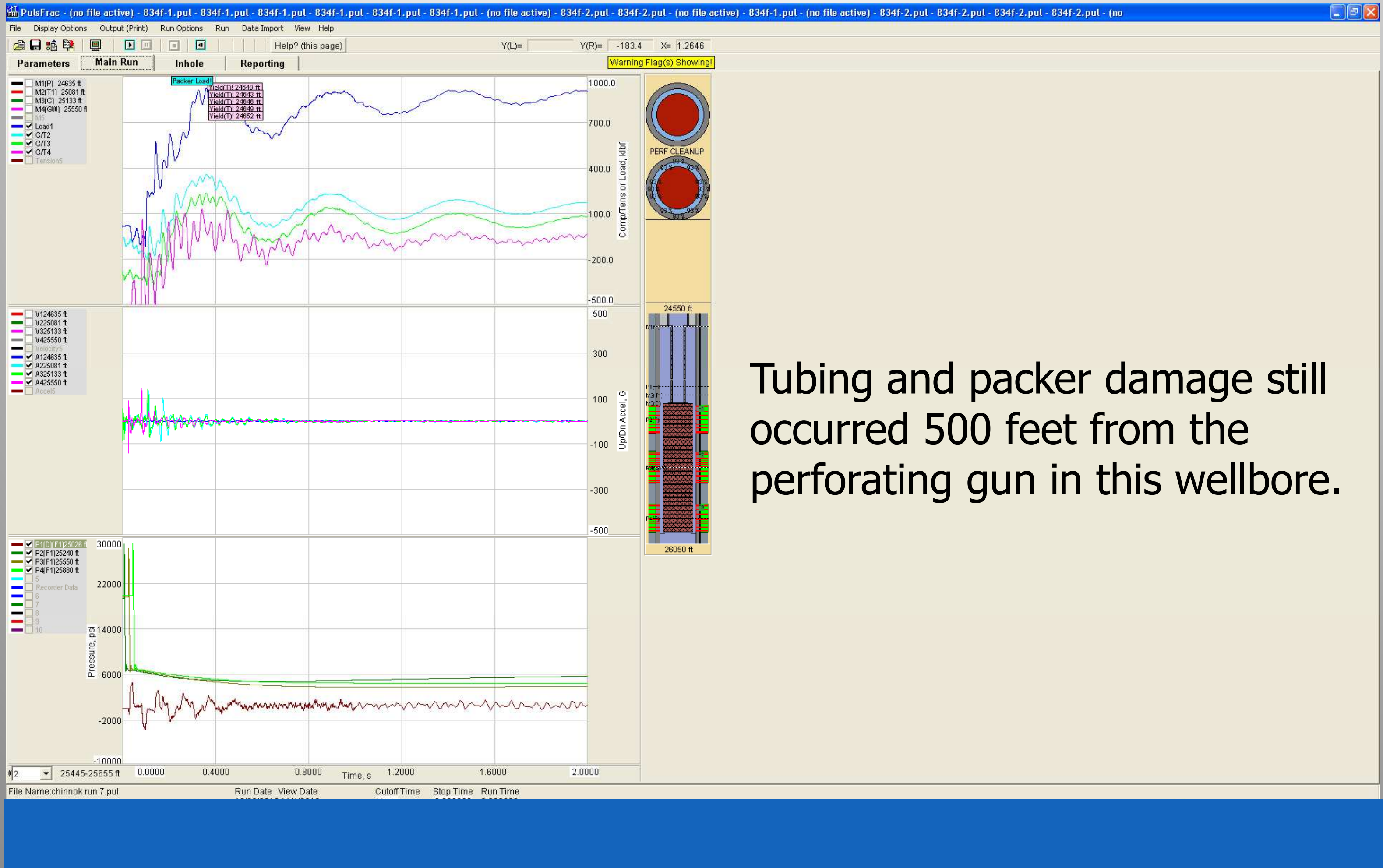
- Risk mitigation to minimize NPT due to the perforating process in critical wells
  - NPT due to mechanical failure of perforating BHA
  - NPT due to mechanical failure of packer and workstring
  - NPT due to mechanical failure of sump packer/ bridge plug
  - NPT due to mechanical failure of liner/casing
- Life-of-well assurances
  - Re-completion applications such as through-tubing perforating effects on bridge plugs

Risk Mitigation

- TCP job modeled with 30ksi system
  - 475klbf Max Rated Load on Packer Body
- General Modeling Template used
- Possible Remedies:
  - More Shock Absorbers
  - Different distance between Packer and Guns
  - Different distance between Sump Packer and Guns
  - Different Grade of Tubing

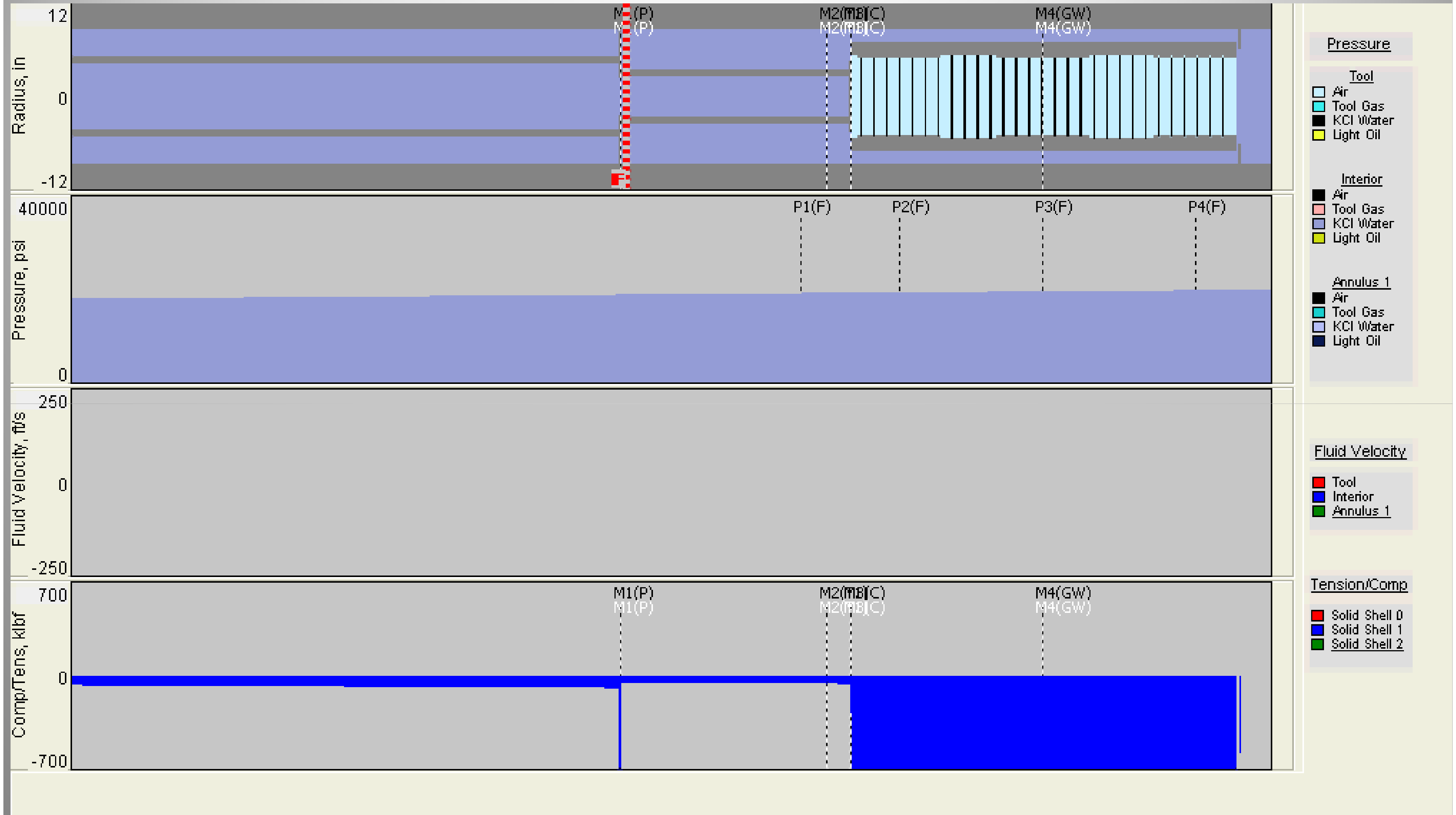


Shock is Not Intuitive



Tubing and packer damage still occurred 500 feet from the perforating gun in this wellbore.

PulsFrac Inhole Video GOM Client



DEEP WATER WEST AFRICA

- Up to 6,000 feet of water
- 120° C BHT
- Sea Water Completion Fluids
- 5 ½” Drill Pipe above the TCP Assembly.
- 7.00” 12-16 spf perforating guns, 39-61 gram BH Charges, zinc cases.

TCP Job Database

Well Name	Perforations		Total Perf (mtrs)	Charge Type	Underbalance	Underbalance Type	Firing Type	Shock Absorber (QTY)	Tubing below PKR (size)	Tubing below PKR (QTY)	Non-Standard Hookup Comments	Observed Damage
	Top Shot (mtrs)	Bottom Shot (mtrs)										
			98	61gm GP	500	Air	Mechanical	0	3 1/2" EU 8RD	2 jts		1jt tbg bent,Pkr mandrel bent
			78	39gm DP	0	Overbalanced	Mechanical	0			Shot with PKR unset	
			14	39gm FP	500	Air	Mechanical		3 1/2" EU 8RD	4 jts		
			57	61gm GP	500	Air	Mechanical	1	3 1/2" EU 8RD	4 jts		Body on shock absorber split.3 jts tbg bent.
			31	61gm GP	500	Air	Mechanical		3 1/2" EU 8RD	4 jts		3 jts tbg bent.
			60	61gm GP	500	Air	Mechanical		3 1/2" EU 8RD	4 jts		Shock absorber mandrel split,tbg bent.
			12	61gm GP	500	Air	Mechanical		3 1/2" EU 8RD	4 jts		Tbg bent
			61	61gm GP	500	Air	Mechanical		3 1/2" EU 8RD	4 jts		Tbg bent
			70	39gm FP	500	Air	Mechanical	0	NC38 Drill Pipe	4 jts		Packer mandrel bent.
			63	61gm GP	0	Overbalanced	Mechanical	0				

Compression Failure of Tubing Joint Directly on Top of Guns.

Failure of Shock Absorbers

- In tight rock shock absorbers are a bad thing.
- The tools cannot cope with the energy.
- As a result they can create a “slide hammer” effect, transferring even more energy to the packer.

Failed outer housing

Page 1 of 1

Rubber elements extruded out of housing

http://firstalert/FirstAlertFileRepository/2C832C90-4C56-4084-9749-0F676E58643E.jpg 2/24/2011

Wide Variances in Reservoir Information Led to Problems

- K values varied up to 150%
- Initial Skin values were much greater than reality.
- Young’s Modulus and Poisson's Ratio were unknown.

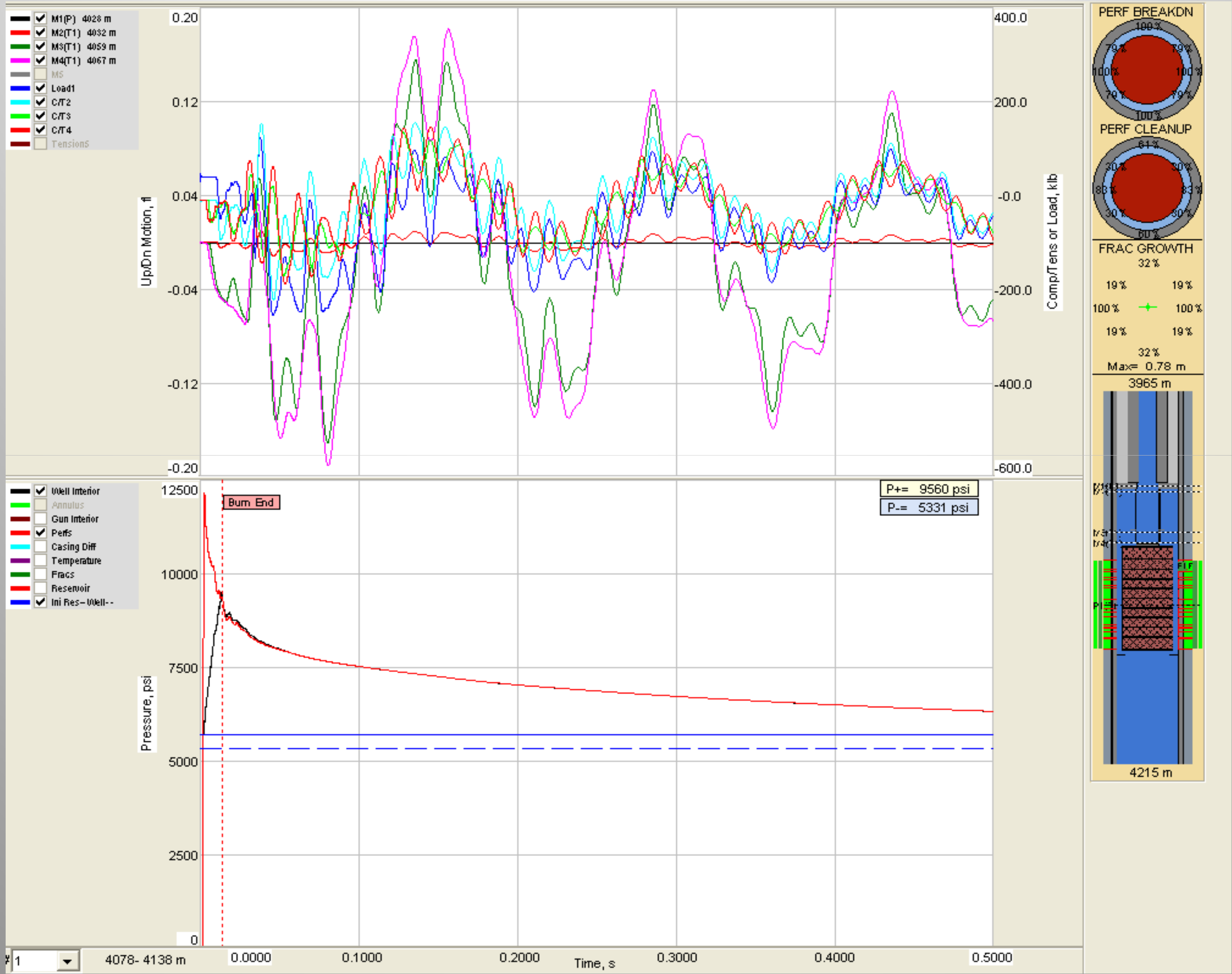
Why are there failures?

- We are detonating 40 kilograms of HMX military grade explosives less than 4 metres from a plug.
- In this operation, there is little we can do to prevent damage
  - Shaped charges are only about 35% efficient, there is plenty of excess energy released to the wellbore.
  - Low permeability means the formation cannot absorb energy fast enough. The energy released must be balanced, therefore tubing is bent, packers and plugs fail or are damaged.
  - The zinc cases are highly energetic and add even more energy to the system.

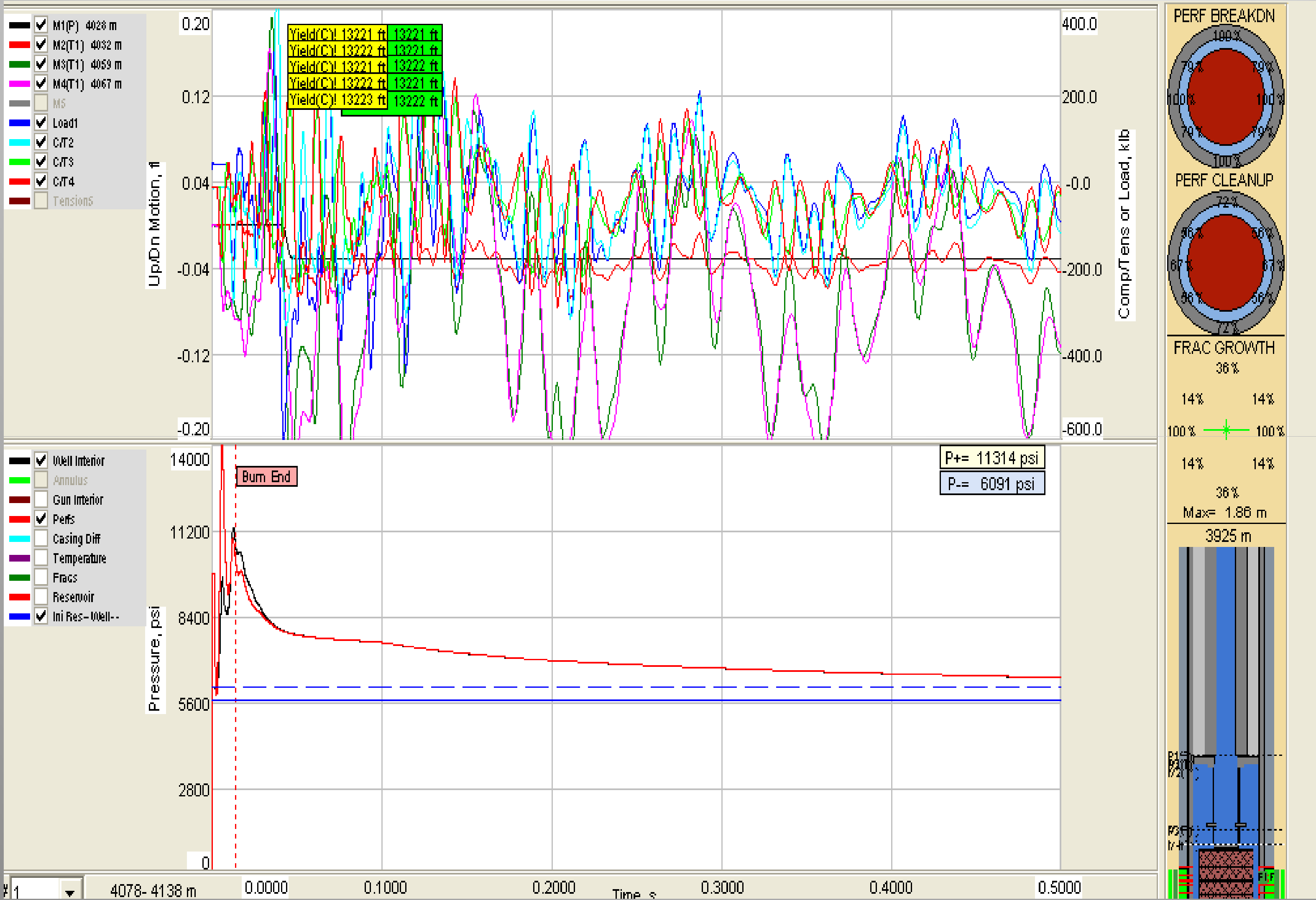
Is bending the tubing a bad thing?

- Sacrificing several joints of EUE tubing may be more desirable than shearing a joint of drill pipe or severely damaging a packer.
- Using all drill pipe below the packer could potentially stiffen the system to the point of over loading the packer.
- Shock absorbers are not effective in low permeability formations and may actually be detrimental.

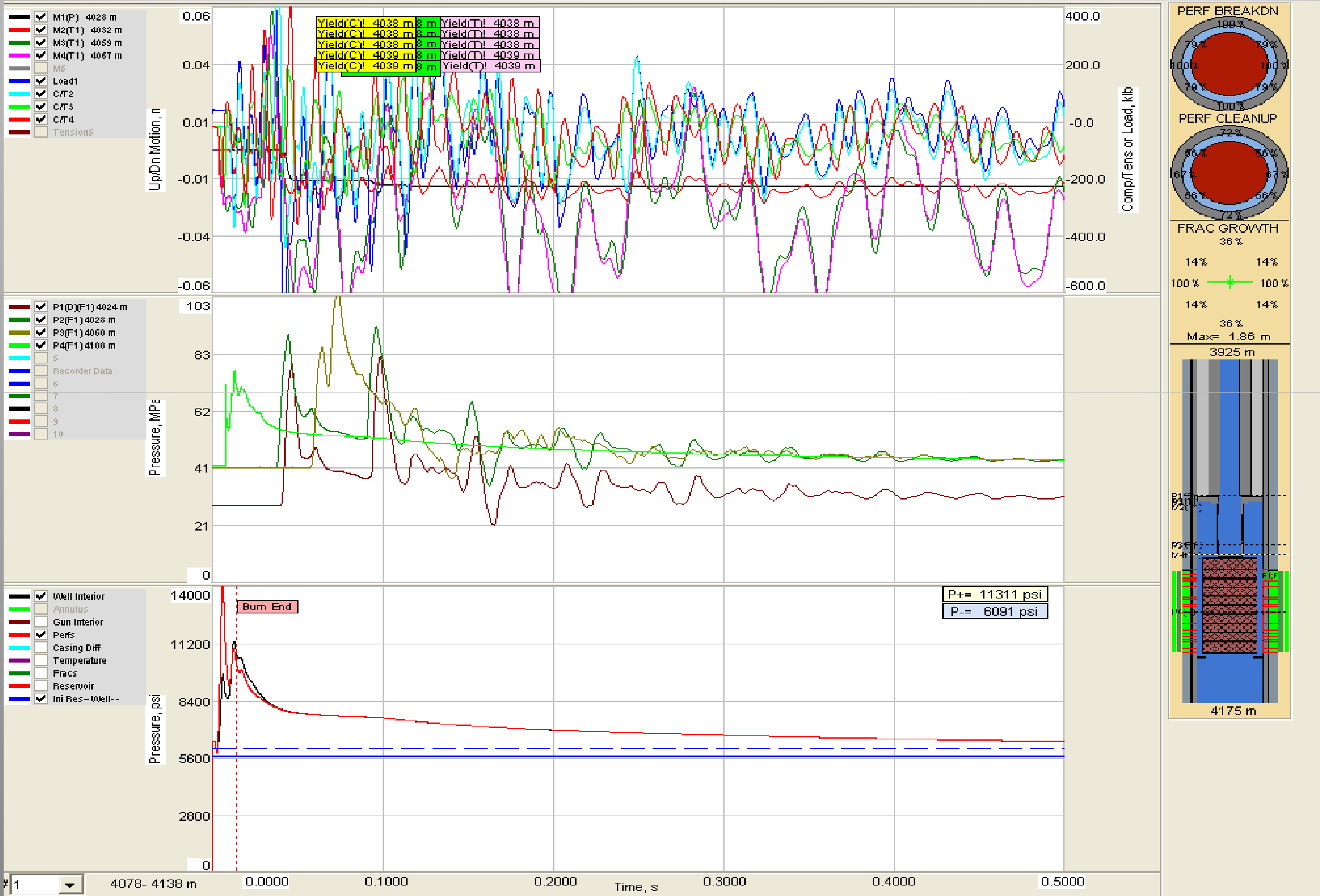
J-XX Run 1 542 mD Permeability



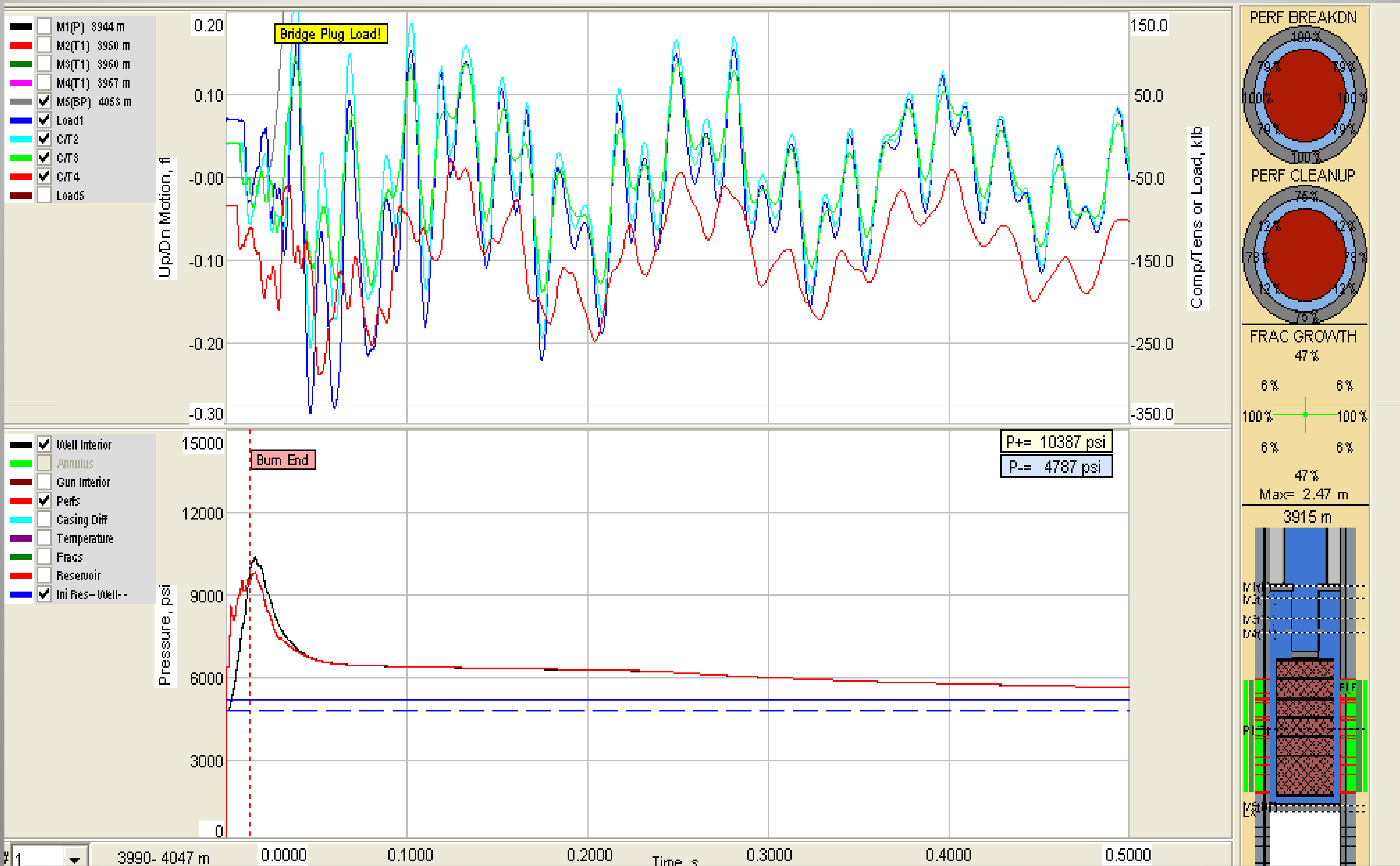
J-XX Run 2 249 mD Permeability



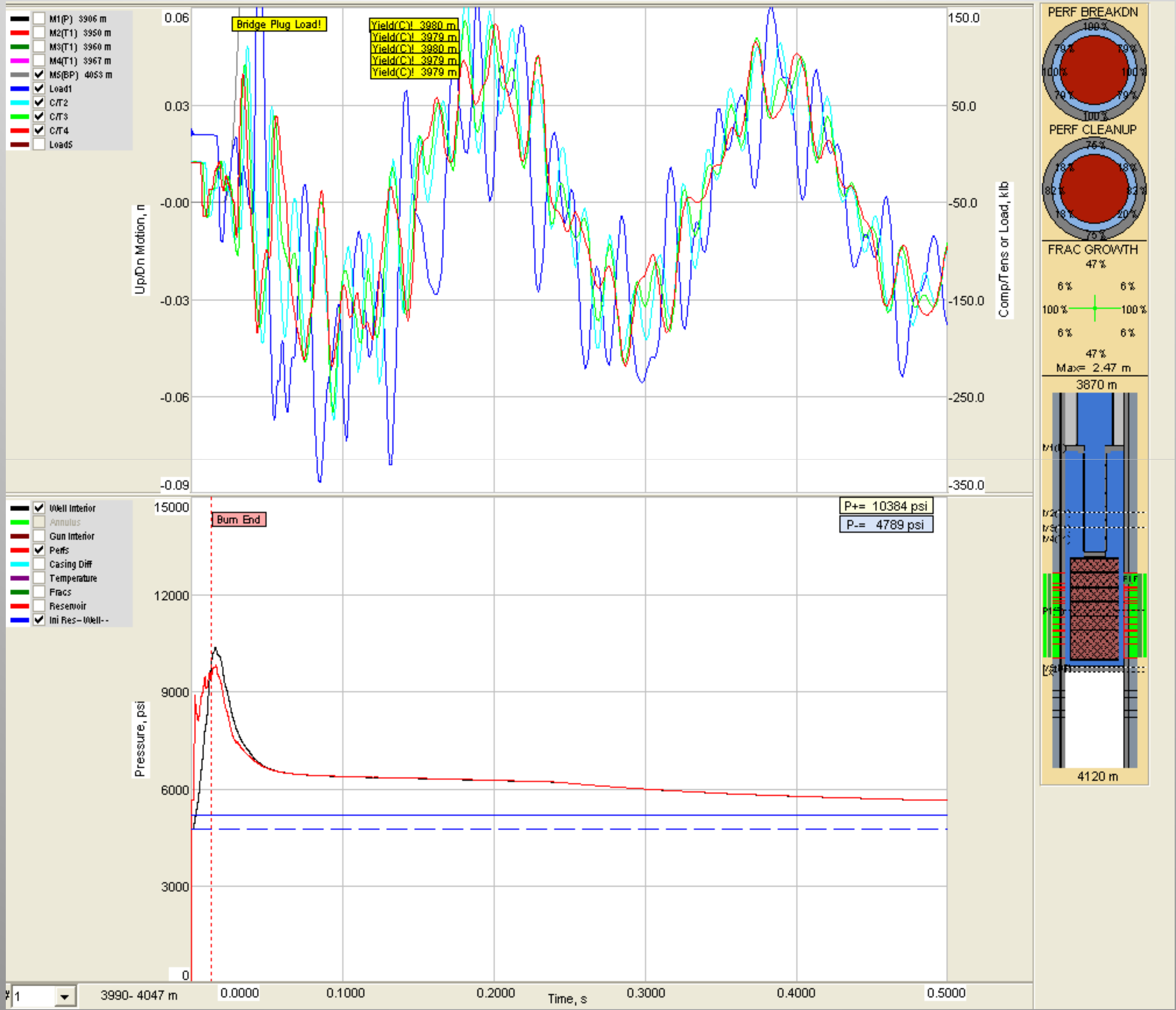
J XX 1 joint of 3 ½" EU



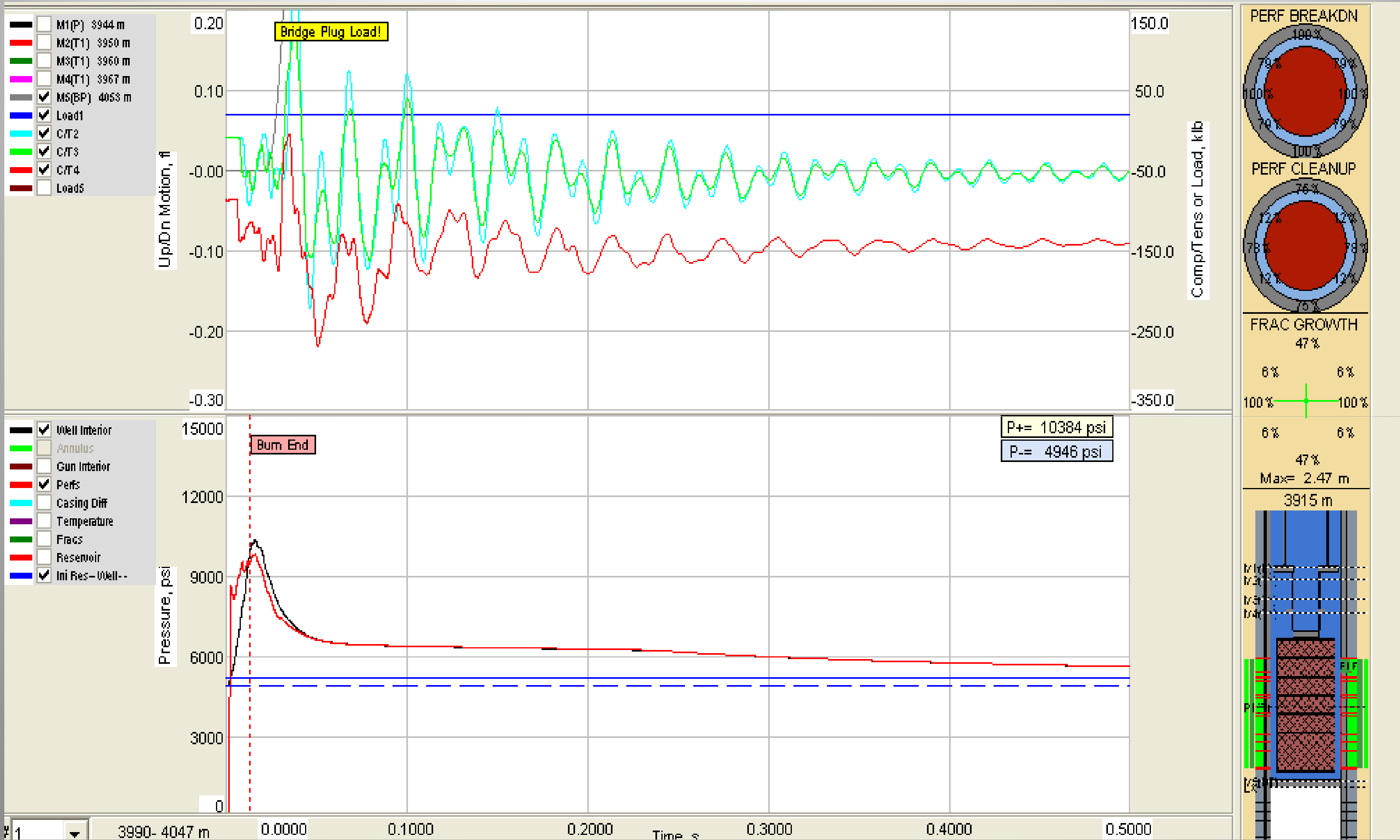
J-XX Upper Completion



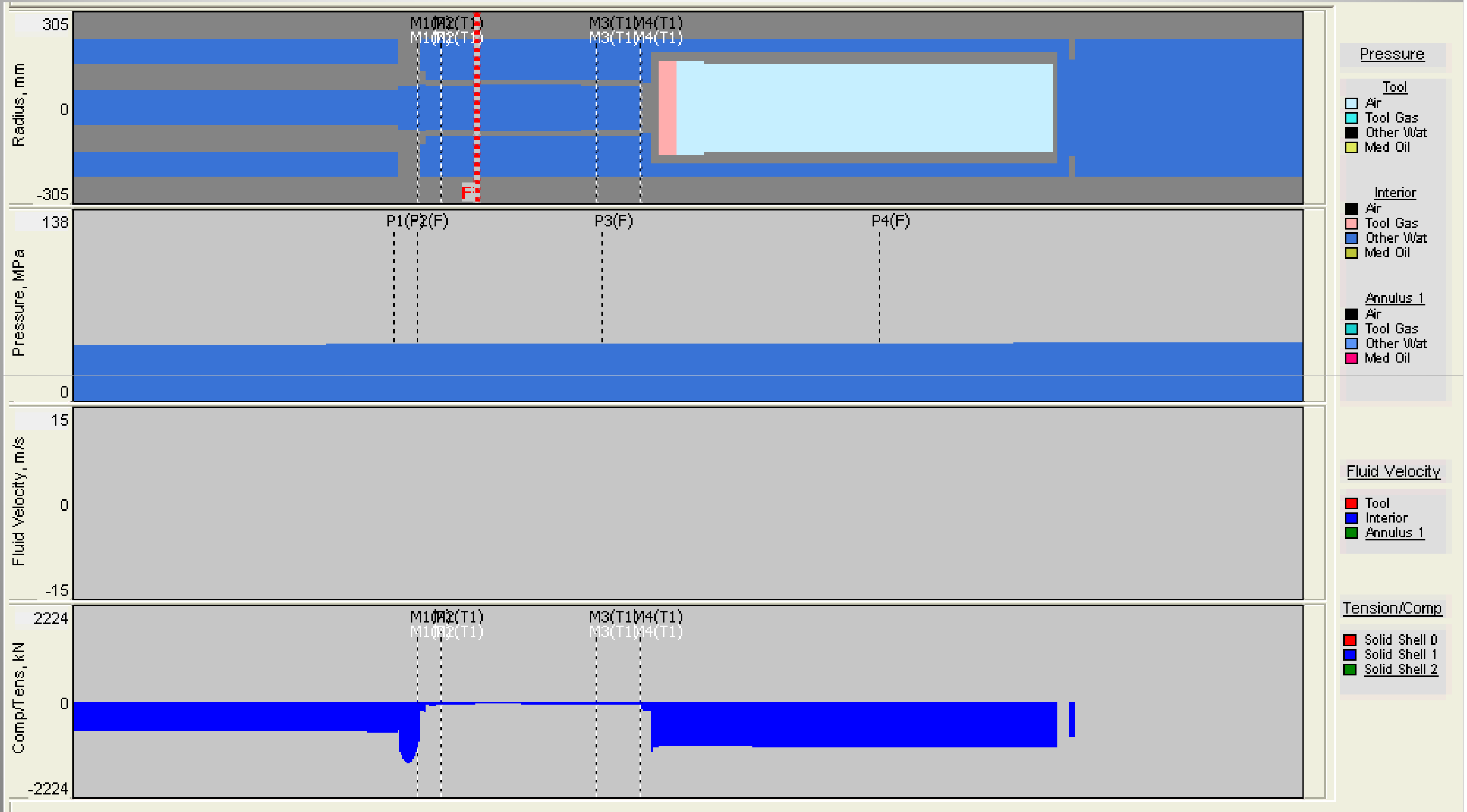
J-XX 8 Joints of Drill Pipe



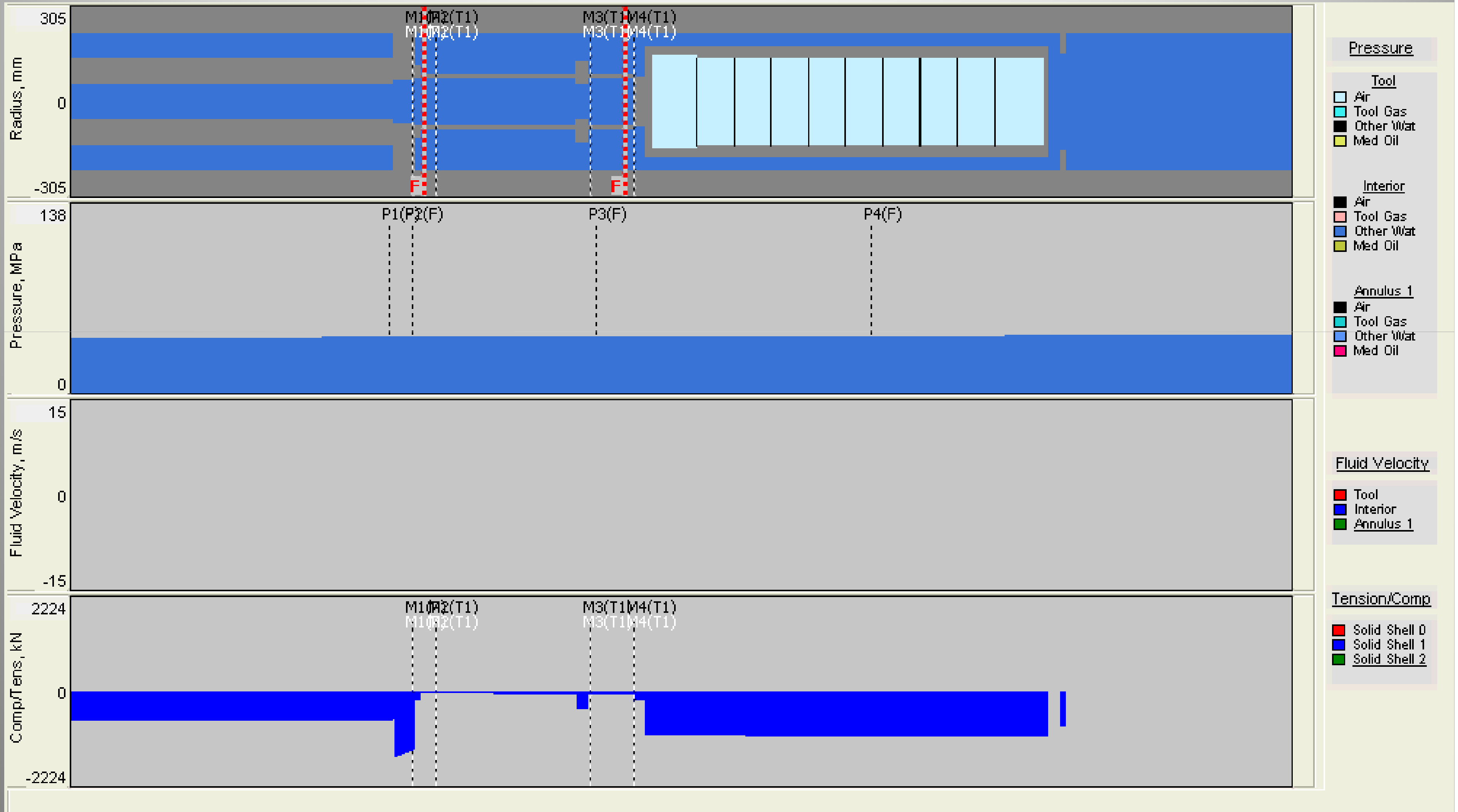
J-XX Packer Unset



J XX Drill Pipe



J XX Tubing, Packer Unset

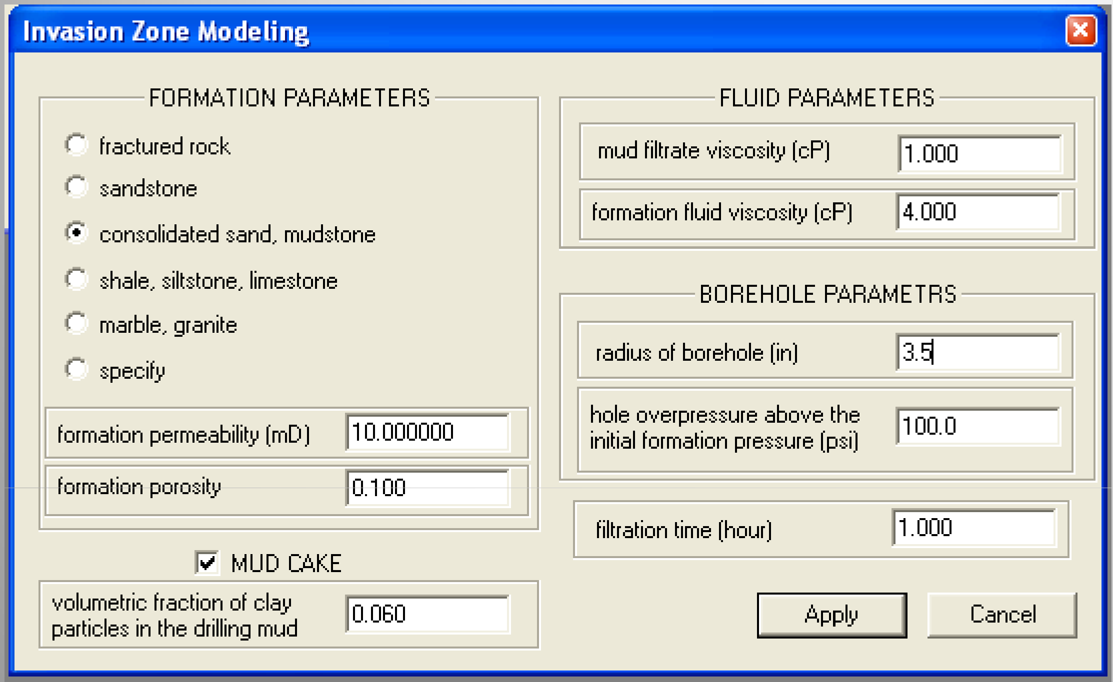


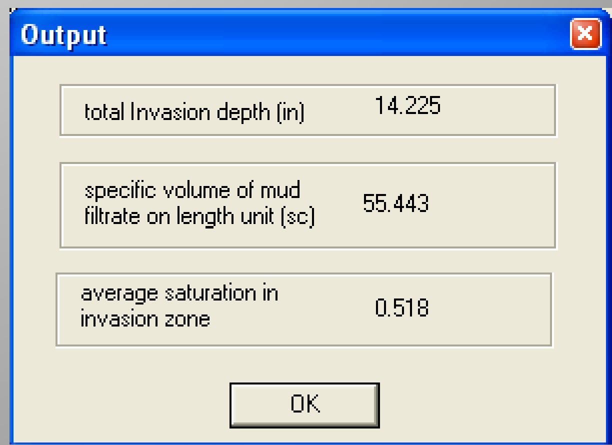
Conclusions

- We need accurate information about the reservoir to make the model work.

1. Permeability-The ability of the formation to accept and absorb gas and fluids generated by the gun detonation are directly related to this number.
2. Young’s Modulus & Poisson’s Ratio- In some cases the rock may actually fracture during the perforating process, especially with zinc cased charges. The elasticity of the rock is another factor that will gauge the ability of the reservoir to absorb energy.
3. A better understanding of formation skin a mud invasion may help.
4. Depth of Invasion- BakerHughes has developed an “applet” to estimate drilling fluid invasion.

Invasion Zone Applet





Conclusions/Limitations

- Although General Modeling Template not exacting, does help Operational Risk Management
- Modeling Template will change with different formation properties
  - High Speed Gauge data allows more exacting behavior for a particular field
- Altering BHA has altered Results
- Run high speed recorders to more fully understand the loading during gun detonation.
- The 39 gram DP charge may help reduce shock due to reduced explosive loading and better formation contact.
- PulsFrac improvements under development.
  - 2D Packer model.
  - 2D Shock Absorber