StimPlan News
Volume 6, Number 1
Phone 1-918-496-2071
June 2001
NSI TECHNOLOGIES, INC.

Young's Modulus, E

Is Young's Modulus an important variable for fracturing? **How is this variable treated** within StimPlan and other models? **Is the treatment of modulus changing** for future StimPlan versions? **Are the calculations different** for StimPlan & E-StimPlan? This newsletter briefly addresses these questions.

Is E Important - It is difficult to choose a "most important variable" for fracturing, but modulus must certainly be considered when making any such choice. This can be illustrated using some basic fracture behavior relations for net pressure and fracture width. As seen in these relations, 'E' is a dominant variable for determining P_{Net} (and thus for determining height growth) for viscosity dominated behavior, and a dominant variable for determining width for tip effect, i.e., toughness or $K_{Ic\text{-}app}$, dominated behavior. Thus, clearly Young's Modulus, E, is very important. NOTE, another important point with regard to modulus is that **it is the ONLY fracturing variable subject to direct measurement** via lab tests on core.

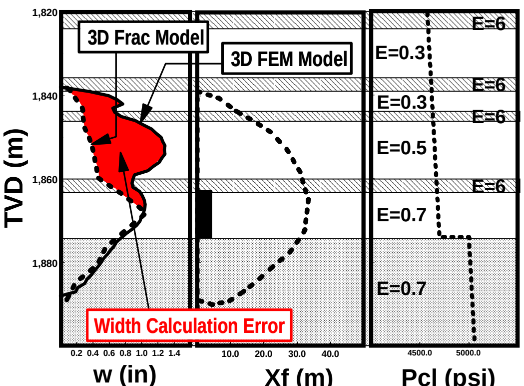
$$p_{net} \propto \left\{ \frac{E^4}{H^4}\left(\frac{\mu\ Q\, x_f}{E}\right) + \frac{K_{Ic-app}^{\ 4}}{H^2} \right\}^{1/4}$$

$$w \propto \left\{ \left(\frac{\mu\ Q\, x_f}{E}\right) + \frac{K_{Ic-app}^{\ 4}\, H^2}{E^4} \right\}^{1/4}$$

How is "E" Used in Models — Presumably modulus is used similarly in all fracture models, and probably used correctly for cases with a uniform value of "E" for all formation layers. In such cases, modulus basically determines the ratio between net pressure in the fracture and resulting fracture width. Unfortunately, a uniform value is seldom an accurate description of geologic reality, and the "correct" treatment of this variable becomes difficult for layered modulus cases. This is discussed in a recent paper, SPE 71654, "Layered Modulus Effects on Fracture Propagation, Proppant Placement, & Fracture Modeling".

StimPlan uses an "average modulus" for layered cases, and has always based this average modulus on relations developed from multiple FEM (finite element method) calculations. Note that this "correct" average value can be quite different from a simple "average over the height", and in fact, layers above/below the fracture strongly affect the correct E_{Avg}. To achieve a correct value, even an average modulus MUST be based on some form of more rigorous calculation, i.e., FEM modeling, as done for StimPlan (discussed more below).

Probably, some form of "average modulus" is common for modeling of layered cases, but other approximations are used. Undoubtedly, these approximations are appropriate for conditions defined when developing the approximations, but in other conditions it is possible for any approximation to yield seriously wrong results. This is illustrated by an example. For this case, a 3-D model was run for a layered modulus case. The exact frac geometry and internal pressure distribution from the fracture model were then input into a commercial 3-D FEM model. The two resulting width profiles (at the well) are compared in the figure. As seen, the correct (FEM) width profile (for the geometry & pressure from the fracture model) is grossly different from widths calculated by the fracture model. The frac model is clearly not using a simple "E_{Avg}" approach, but the approximations used to handle the layered modulus have



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StimPlan User Courses are being presented. These one-day courses are designed as hands-on interactive instruction on the application of **StimPlan** and **E-StimPlan** to solve many petroleum engineering stimulation design/analysis problems. The objective is to maximize your ability to solve completion and stimulation problems using the "**Five Function**" approach of the StimPlan package. These ***5 functions***, which should form the basis of any fracturing software are: 1) **Data Analysis** including ability to handle and analyze fracturing pressure data and post-frac production data, 2) **Fracture Geometry Model** (while this is an important part, it is only one of 5 essential functions), 3) **Economic Analysis** in order to determine what type of treatment is desired based on realistic data & numerical fracture/reservoir/economic simulation, 4) **Automatic Pump Schedule** generation to eliminate wasted trial & error data input to arrive at a final schedule, and 5) **Production Analysis** (type curve analysis and numerical simulator production history matching) for post-frac production analysis. If you are interested in hosting/attending one of these interactive courses, please contact us at info@nsitech.com.

StimPlan/E-StimPlan Development Features & Plans

StimPlan	Status	Target
Upgrade 3-D Numerical Reservoir Model to include non-Darcy flow	**Beta**	**3rd Quarter 2001**
Integrated (Fracture Geometry, Reservoir Model, Economics) Optimization	Version 4.00	Released
Post-Frac Production Analysis (Fetkovitch/Carter Analysis, History Match)	Version 4.00	Released
Production Decline Analysis (Agarwal-Gardner Type Curves)	Designing	
Horizontal well/Multi-fractured horizontal well analysis/optimization	**Beta**	**3rd Quarter 2001**
Graphical, Log Style input for Geo-Mechanical & Fluid Loss Layering	Version 4.10	Released
Input log data from LAS files for aid in defining Geo-Mechanical Input	**Beta**	**3rd Quarter 2001**
Measured Depth/TVD Option	**Beta**	**3rd Quarter 2001**
Enhanced Database Features (fluids & proppant)	Version 4.10	Released
Enhanced Database Features—Rock Mechanics, Pipe Friction	Version 4.10	Released
Pre-Closure Frac Pressure Decline Analysis for Permeability (Ispas, et al)	Designing	
Post-Closure Frac Pressure Decline Analysis for Permeability (Nolte, at al)	Designing	
E-StimPlan		
Finite Element elasticity for layered modulus cases	Version 4.00	Released
"N" Frac Simulations (multiple fractures in separate vertical layers)	Version 4.10	Released
Upgrade to Planar 3-D Model — StimPlan 3-D	**Beta**	**3rd Quarter 2001**
Upgrade Decline Permeability Analysis w/time & closure varying "stiffness"	Future	

Production Analysis

Did you know that StimPlan (and E-StimPlan) includes full facilities to analyze pre–/post-frac production data from type curve analysis to 3-D reservoir simulator history matching? This answers such questions as **"What is the importance of perforated interval length?"**, **"Is Non-Darcy flow important for this case?"**, etc.

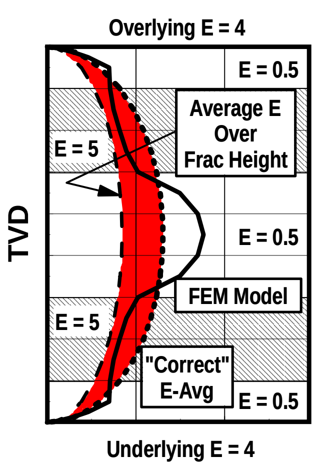
Check our web site — http://www.nsitech.com/ – or visit our booth at the SPE Annual Meeting in New Orleans (October, 2001) for more information.

(StimPlan 4.00 , Continued from page 1)

led to serious errors in calculating fracture width. The difference is so great that it undoubtedly affects calculated fluid efficiency; thus, designs based on this modeling are incorrect!

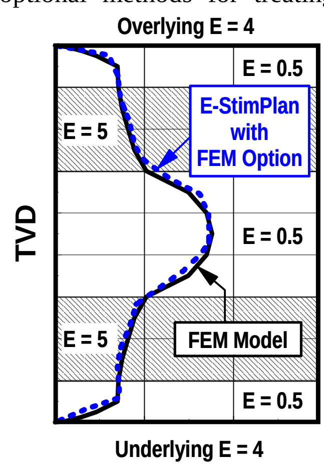
StimPlan Modulus Calculations are being updated for the upcoming version. In terms of an "average E" approximation, StimPlan has always, we believe, taken a more sophisticated approach than many if not most fracture geometry models. This comes from an analytical approximation used to generate the E_{Avg} for any case that is based on multiple FEM calculations. That is, the average used was NOT a simple "average over the fracture height", but rather was a modulus which gives the correct average width (thus preserving the correct material balance of the solution). However, recent work has indicated that a finer approach would be beneficial. In addition, quantum leaps in computer speed since the original analytical approximation was derived made it feasible to both generate a new, "finer" approach, and to routinely use such a finer approach in normal StimPlan simulations.

An example of the new StimPlan E_{Avg} is seen in the figure. This new approach was based on more than 200 FEM calculations. In addition, 40 additional FEM calculations were made with a range of layered E cases. For these 40 cases, average error between the new StimPlan E_{Avg} and the correct average modulus (modulus giving the correct average width) from the FEM results was 2.5%. The maximum error was 11%, but for cases where the total range of modulus values was less than 5:1, the maximum error was only 2.1%. In the example, the "correct" E_{Avg} is 1.615×10^6 psi (i.e., using this value of E yields a calculated frac width with the same average width as the actual profile), with the StimPlan analytical model giving E_{Avg}=1.612. A simple "average over the height" gives E=2.5, and causes significant errors by calculating a much too narrow fracture.



StimPlan vs. E-StimPlan (3D) — E-StimPlan (and E-StimPlan 3D) allows two optional methods for treating modulus in the calculations.

- First, the "normal" StimPlan method can be used where an equivalent, uniform "average" modulus is used. The average modulus is computed to give the correct average width; thus, allowing the model to compute the right material balance, fluid efficiency, etc.
- Optionally, FEM calculations can be used to determine the pressure width behavior. As an example, the E-StimPlan width profile is compared to FEM calculations (for the layered example used earlier) in the figure.



Which Should I Use — As a rough rule, FEM calculations should be used anytime the range in modulus (i.e., ratio of the largest to smallest modulus value) is greater than 2:1. For ranges in modulus less than this, actual local width variations are generally quite small. However, as with any statement regarding fracturing, there can certainly be cases where even a 2:1 difference in modulus can create local width variations that are important or even critical (though this would probably be rare).

How Can I Check — my model? One simple test would be to simulate a case with near perfect height confinement, and then vary modulus for over and underlying zones. If this does not affect the answer, then layered modulus is not being correctly treated by the simulation!