Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Stuck Casing Mitigation, Raising Situation Awareness During Casing/Liner Installation Based on Real Time Friction Coefficient Analysis

Gudrun Hillbrand, Manuel Fasching, David Lentsch and Gerhard Thonhauser

hillbrand@erdwerk.com

manuel.fasching@gmx.com

lentsch@erdwerk.com

gerhard.thonhauser@unileoben.ac.at

Keywords: stuck casing mitigation, running casing model

ABSTRACT

Running a casing/liner is a technically and economically crucial operation. The increasing complexity of trajectories, as well as larger casing/liner diameters used in the geothermal industry, has caused problems with liner running operations in the past. Dealing with a stuck casing/liner consumes time and money, lowering the overall profitability of the project. To address this challenge, applications (friction model and analysis portal) and a risk diminishing workflow have been designed to enhance decision making, whilst raising situational awareness during casing/liner running. Before running the casing/liner, basic input parameters are processed on the basis of a soft-string model. The friction model generates a broomstick diagram plotting “hook load over running depth” which represents a variable set of different open hole (OH) and cased hole (CH) friction coefficients. During the actual casing/liner running job, the recorded hook load sensor data is used to calibrate the model by iteratively adjusting the OH and CH friction coefficient. After the dominant OH friction coefficient is identified, predictions for the upcoming hook load trends can be made. In this way, small deviations in hook load development over running depth can be detected and proper actions can be taken. To date, the tool has been run on more than 10 reference wells in the Molasse Basin (Bavaria, Germany) utilizing predominantly 13 $^{3}/_{8}$”, 9 $^{5}/_{8}$” and 7” liners. The outcome is a database of different dominant friction coefficients as well as hook load patterns acquired during the liner installations. Collected and analysed data, processed in the analysis portal, manages to quantify the impact of individual framework parameters such as well trajectory, friction coefficient, mud weight on the likeliness of casing getting stuck. With the aim of an overall improvement in quality of hook load trend interpretation, individual hook load patterns have been analysed in detail. Identifying the shape of a critical hook load pattern works as an early warning system, raising awareness and diminishing the risk of stuck casing/liner for future installations.

1. INTRODUCTION

The South German Molasse Basin (SGMB) in Bavaria, Germany is one of the most promising geothermal reservoirs of Germany with 26 deep geothermal projects realized between 1998 and March 2018 (Flechtner und Aubele, 2019). With the necessity for high production rates (above 50 l/s up to 160 l/s) for economical production, casing/liner strings must be designed using large diameters, keeping the pressure losses along the casing/liner down to a minimum. The typical well design in the SGMB can be divided into three general design groups, depending on the number of sections and their final bit diameters. Wells drilled within 4 sections, ending with an 8 $^{1}/_{2}$“, or 6 $^{1}/_{8}$” bit diameter in the reservoir section, and wells drilled within 5 sections, ending with a 6 $^{1}/_{8}$” bit diameter in the reservoir section, as shown in the table below. Well depths of the analysed wells range from about 2,500 m TVD and 2,600 m MD, to 5,000 m TVD and 6,000 m MD. The well paths are mostly J-shaped with two built sections, combined with changes in azimuth within the reservoir.

Table 1: Well design overview for typical wells in the South German Molasse Basin

<table>
<tr><th colspan="3"></th><th></th><th>Bit Diameter</th><th>Casing Size</th><th>Average Casing / Liner Length</th></tr>
<tr><td rowspan="4">Group 1</td><td></td><td rowspan="5">Group 3</td><td>Surface Casing</td><td>26” to 23”</td><td>20” to 18 $^{5}/_{8}$”</td><td>750 – 900 m</td></tr>
<tr><td rowspan="4">Group 2</td><td>Surface Casing / Production Casing / Production Liner</td><td>16” – 17 $^{1}/_{2}$”</td><td>13 $^{3}/_{8}$”</td><td>900 – 1,500 m</td></tr>
<tr><td>Production Casing / Production Liner</td><td>12 $^{1}/_{4}$”</td><td>9 $^{5}/_{8}$” to 10 $^{3}/_{4}$”</td><td>500 – 2,000 m</td></tr>
<tr><td>Production Liner / Pre-drilled Liner</td><td>8 $^{1}/_{2}$”</td><td>7”</td><td>0 – 1,800 m</td></tr>
<tr><td></td><td>Pre-drilled Liner</td><td>6 $^{1}/_{8}$”</td><td>5”</td><td>0 – 1,000 m</td></tr>
</table>

Especially the installation of long (up to 2,000 m) 9 $^{5}/_{8}$” liners is considered challenging, as the well paths are often inclined in the 9 $^{5}/_{8}$” section (40° to 60°). Past challenges with liner running necessitated the identification of the most probable causes for stuck liners. The resulting analysis of hook load data was the inspiration for this study. Casing/liner running data sets of several reference wells have been analysed in detail. In the friction model and comparison portal created for this purpose, the data is processed and juxtaposed. The outcome is a risk diminishing workflow for future casing/liner running jobs.

2. OBJECTIVE

The objective of this study is to identify risks before problems occur while running the liner. An essential requirement to assess these risks, is to compare the recorded hook load sensor data with the predicted hook load over depth. Therefore, a friction model is run prior to job execution, showing the theoretic hook load trends based on a set of friction coefficients. While running the liner in hole, the engineer is equipped with a broom stick diagram of potential hook load trends. While running the liner, the previously assumed friction coefficients can be adapted, in order to fit the actual recorded hook load sensor data. This way, the dominant friction coefficients can be identified, while calibrating the model using field data. With the knowledge of the dominant friction coefficient, the hook load progression to the total depth (TD) can be predicted more accurately and deviations from the norm can be recognized more easily.

Besides the overall hook load trend, it is the shape of the recorded hook load data, referred as hook load pattern, which is key to assess the situation. The differentiation between smooth and critical pattern shapes, and the identification of parameters that cause those deviations, are of great interest when it comes to decision making in the field. Therefore, different hook load patterns of reference wells have been examined in detail in the analysis portal in order to identify a combination of key indicators, which provide a clearer picture, if a liner or casing is prone to become stuck.

3. FRICTION MODEL – SIMULATION OF HOOK LOAD TRENDS

The friction model, an application designed using Microsoft Excel, can be run prior to and during execution of casing/liner running. Using the soft-string model implemented by Johancsik 1984, it simulates the hook load progression during the casing running process for a set of different friction coefficients. As a result, the expected hook loads for each set of friction coefficients is plotted over running depth. While running the casing/liner in hole, the actual hook load sensor data of the running job is imported into the model and used to fit the simulated hook load trends to the real time data by adjusting the friction coefficients for the best fit.

3.1 Physical Background

Pipe drag is the incremental force required to overcome, to move a string of pipes (either casing or drill pipe) downwards into a wellbore. Several root causes for excessive drag include: sloughing or tight boreholes, differential sticking, key seats, hole cleaning problems, as well as sliding wellbore friction. However, sliding wellbore friction is the only source for drag which is not directly related to problematic conditions in the wellbore and is therefore the main cause in wells without cleaning issues. As drag increases with depth and inclination, deep directional wells tend to be more troublesome. (Johancsik et al., 1984)

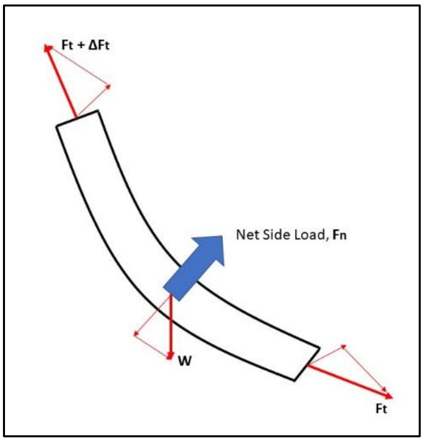

Figure 1: Force balance on a pipe element (adopted from C. A. Johancsik, D. B. Friesen, Rapier Dawson)

The developed application uses the torque and drag model proposed by Johancsik in 1984 for the simulation of the status of the pipe in the wellbore. Despite its simplicity, this model has been used widely for planning and execution of projects in the industry and is referred to as one of the standard models (Mitchell et al., 2007). This model assumes, that the overall drag is provoked by sliding wellbore friction, respectively sliding friction forces, resulting from contact of the steel pipe and the wellbore. Other origins of drag (like bending stiffness of the pipe) are not considered in this model, leading to the name “soft-string” model. Several “stiff-string” models have been established over the years, but no industry standard has been developed (Mitchell et al., 2007).

Sliding friction in the borehole is affected by two factors, the normal contact force as well as the friction coefficient (or friction factor) among the pipe and hole contact surfaces. The outcome of multiplying these two factors is the magnitude of the sliding friction force.

$$F_f = \mu * F_n \tag{1}$$

where F_f, μ, F_n are friction force, friction coefficient, and normal force (net side load).

Two factors that contribute to normal side force between the contact surfaces are considered: gravity and borehole curvature. Figure 1 illustrates a force balance on an element of pipe, the forces and the contributions to normal force are indicated.

Rearranging the equation above, the sliding friction coefficient is the ratio of the friction force and the normal force. This value depends on different friction types along the well path as well as different contacting materials e.g. pipe/cased hole or pipe/open hole (Johancsik et al., 1984). The calculation splits the string into small increments and calculates each increment from bottom to top, beginning with the lowest end of the string proceeding upwards. The incremental pieces of axial loads of the string elements are added up, the result is the total surface hook load of the corresponding running depth. Since there is no rotational movement of the casing/liner string while running downhole, the examined casing/liner hanger systems are referred to as non-rotational systems. Therefore, the application only takes tension increments into account, while torque is not considered.

3.2 Model Workflow

Basic Input Parameters

General information: This set of data includes all important information about the wellbore and the planned operation. This includes: setting depth of the casing/liner, OH/CH transition, mud weight and fluid level inside the borehole. The latter is important for running pre-drilled production liners after stimulation and well testing operations where the static fluid level is below ground level.

Well geometry: Actual well trajectory from survey data, including measured depth, azimuth, inclination and dogleg severity for each meter measured depth is fed into the model. If there are only survey points available, the data set has to be interpolated using a linear interpolation.

Casing/liner, drill pipe data: This data set contains the grades, weights and installation lengths of each string component. In the case that a tapered casing/liner or a drill pipe was used to run the liner downhole, several string components are used. The tensile yield and position of the weakest point are vital for the depiction of operational thresholds.

Block weight: The block weight is an additional weight to be added to the calculation and varies from rig to rig. Since the weight is a major quantity, adding the exact block weight is significant.

Friction coefficients: The calculation is performed for different sets of friction coefficients, which are then iteratively adjusted to find the best approximation to the real time data set while running the liner in hole.

Hook load sensor data: Added stepwise while running the casing/liner in hole, the actual hook load sensor data is used to find the dominant friction coefficient, by comparing the simulated hook load development to the hook load field data.

Friction Coefficient Matching

The simulation is carried out for the operations of running in hole (RIH), pulling out of hole (POOH) and neutral load. The outcome is displayed for comparison in a broomstick diagram plotting hook load over running depth.

Figure 2 shows a typical broomstick diagram after the simulation has been run for all six friction coefficient sets. The red dashed line represents 80% tensile yield of the weakest component in the string, while the black dashed line represents the end of the cased hole section and the beginning of the open hole section. POOH curves give an indication if the point of no return for running out of hole has been exceeded for the corresponding friction coefficient. The point of no return is reached as soon as the POOH curve intersects the line at 80% tensile yield. The RIH curves are used to fit the simulated trends to the hook load field data. The friction coefficient combinations are adjusted until a satisfying match is achieved and one RIH curve approaches the real time data trend. Unknown borehole conditions, like the specific contacting materials (lithology, geology) downhole, or the degree of lubrication at different depths in the well strongly influence the sliding friction coefficient. The outcome of the procedure is expressed as a single pseudo friction coefficient for open hole and for cased hole representing average conditions (Johancsik et al., 1984).

Figure 3 shows an adjusted case of friction coefficient combination after the iterative approach. The green line represents the real time hook load progression during the liner running process.

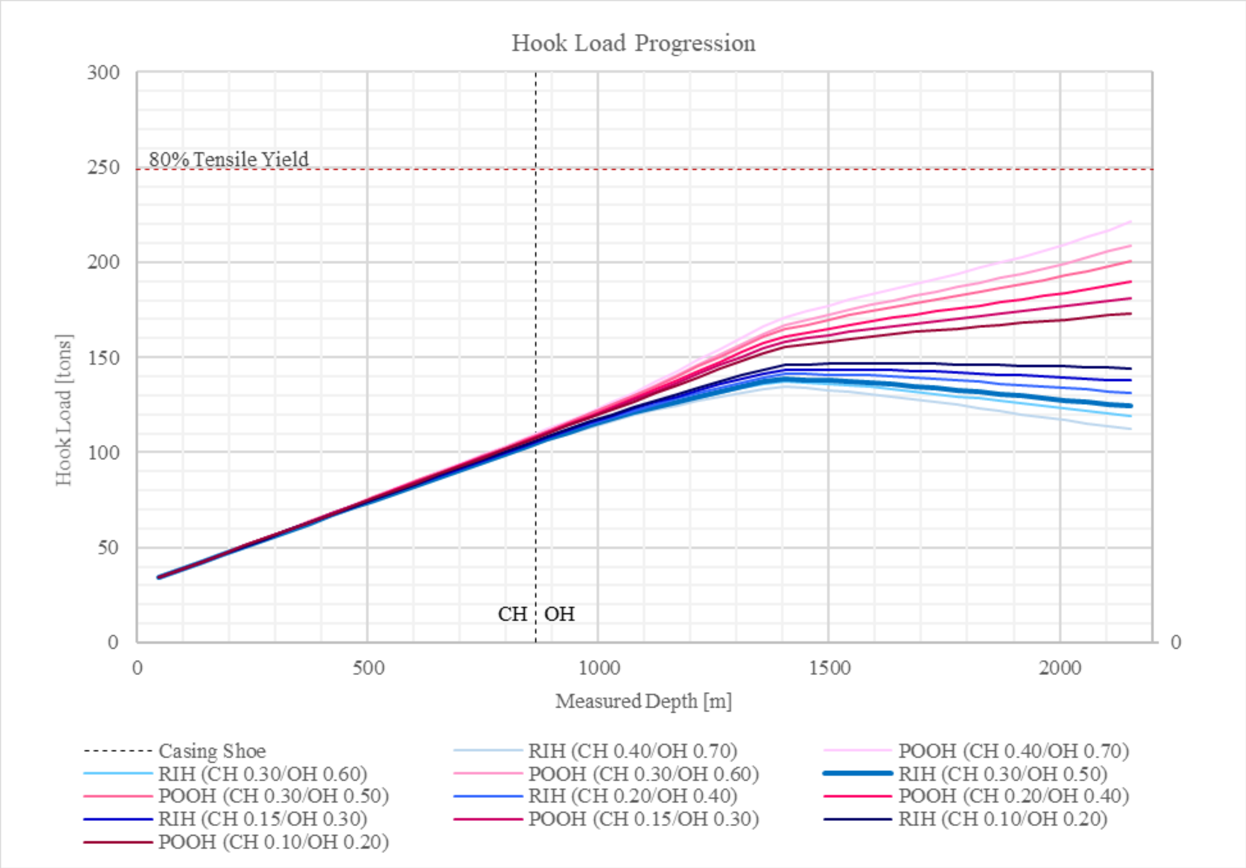

Figure 2: Typical broomstick diagram for RIH and POOH

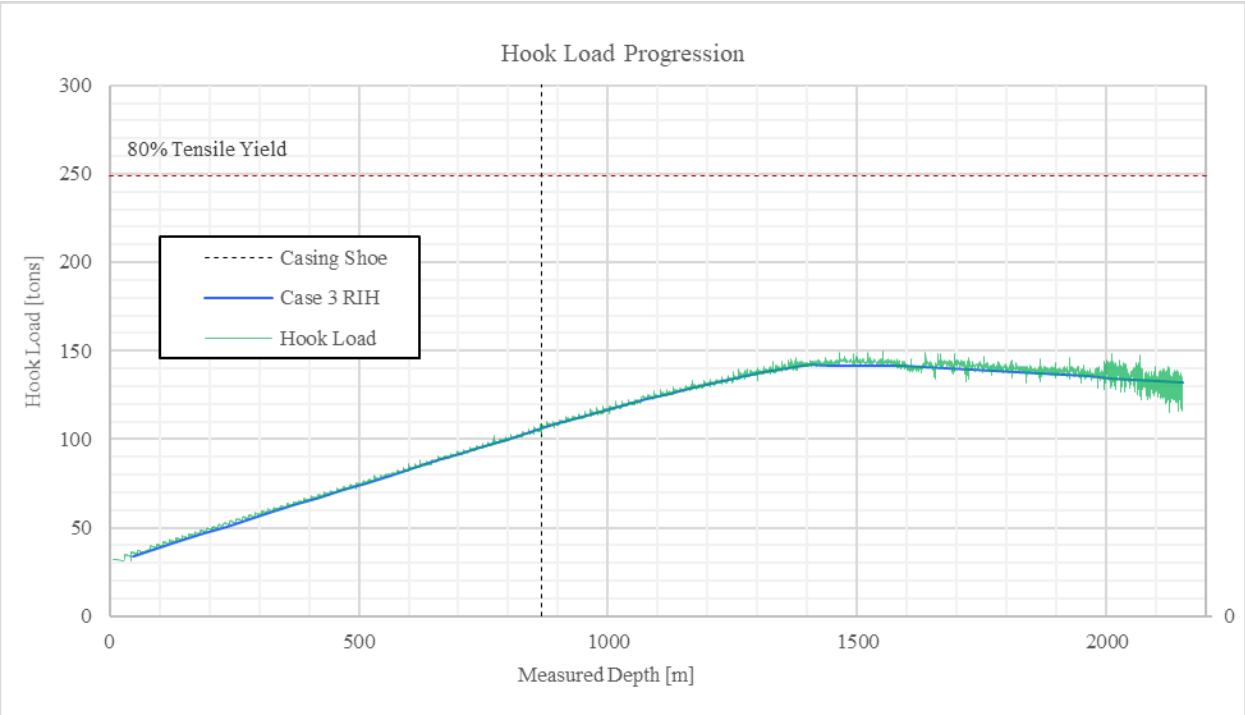

Figure 3: Friction coefficient iteratively matched

4. ANALYSIS PORTAL - IDENTIFICATION OF CRUCIAL FRAMEWORK PARAMETERS

In the "analysis portal", the respective well parameters (including outcome parameters of the friction model) of each well and casing/liner run are collected and processed. The portal operates as a large database where gathered data is analysed in cross plots for crucial individual framework parameter identification for each well. Additionally, the portal serves as comparison platform, juxtaposing central parameters for selected wells.

4.1 Sensor Data Interpretation

For the purpose of analysing different liner running operations in terms of hook load and friction, the running process is visualized. This is achieved by plotting hook load sensor data over measured depth.

Figure 4 shows the typical picture of an unfiltered plotted hook load progression. Throughout the entire running depth, the data points around 20 tons clearly indicate that the string is in slips at the time of measurement. The remaining 20 tons are the recorded specific block weight of the operating rig. The rather loose data points between the data accumulations refer to measurements taken while the slips are removed and the weight on the hook increases again. Points of considerable higher hook loads are recorded during pick-up, increasing the weight due to pulling the string. For a closer analysis, like the identification of delta hook load, delta bit depth, and casing running speed, the data set has to be filtered.

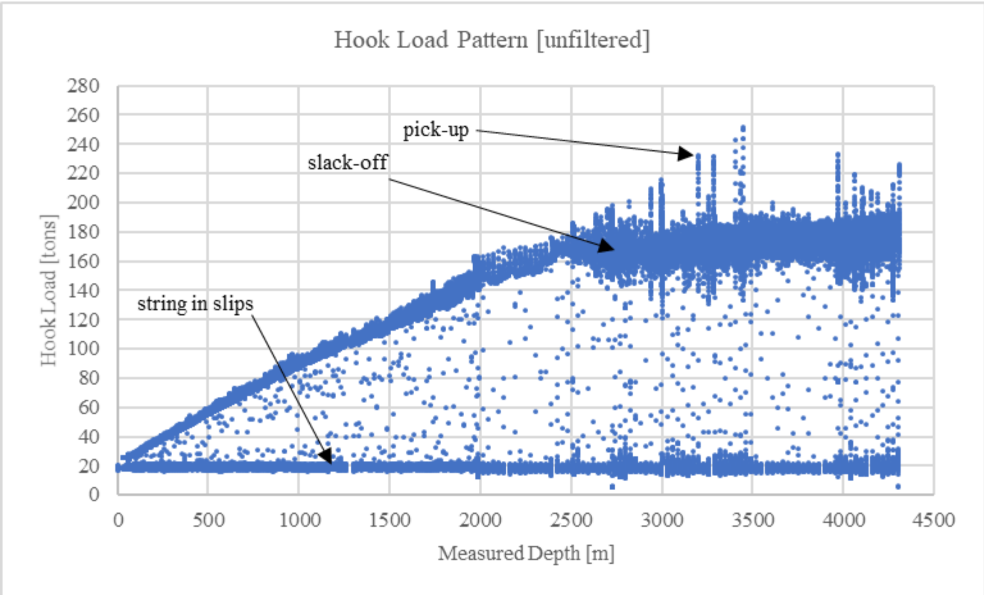

Figure 4: Typical hook load progression during liner installation (raw data, unfiltered)

The "data cleaning" is done by eliminating all data points where the string is not RIH. An example of a typical hook load pattern after data filtering is shown below in Figure 5.

Figure 5 explains the major characteristics of a hook load progression pattern. The first slight decline of the slope is observed at a depth of approximately 1,300 m, indicating the point where the build-up section of the well launches. Due to the inclination of the well, a small amount of the adjusted pipe weight is absorbed and transformed as normal force. The slope drops further around at 1,990 m. At this point in the operation, all liner pipes have been connected and run downhole. This includes the liner hanger, with the preinstalled liner setting tool, forming the cross over from liner to drill pipe. Since drill pipes are usually less heavy than casing pipes, the hook load increases less rapidly. The black dashed vertical line indicates the casing shoe, where the transition between cased hole and open hole is located. From that point on, the pattern deployment widely spreads, with a larger discrepancy of hook load data points than in the cased hole section.

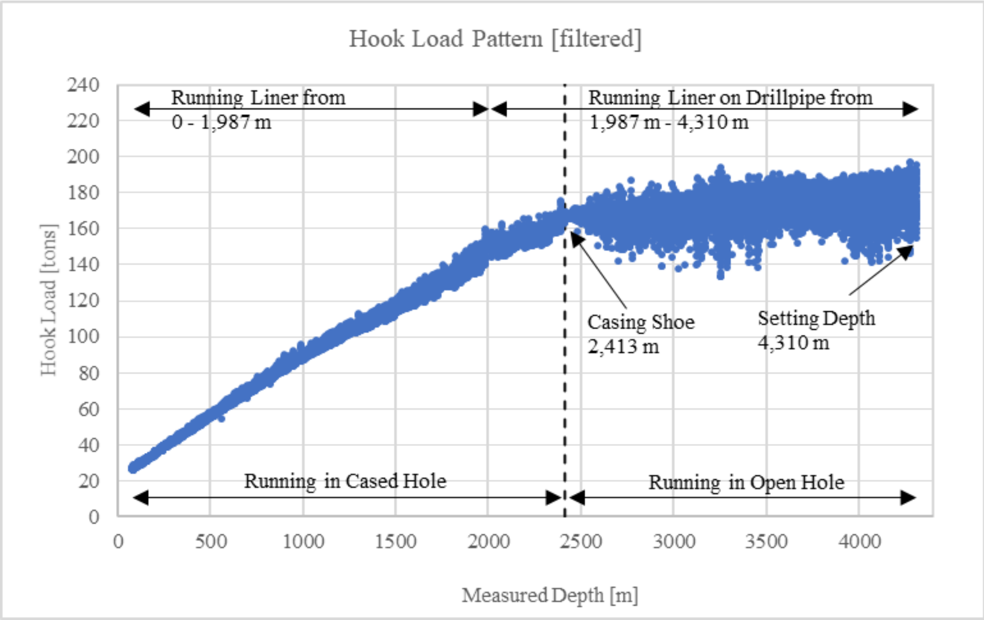

Figure 5: Typical hook load progression during liner installation (filtered)

The spreading of the pattern can be explained by taking a closer look at the data set. Figure 6 shows that besides kinetic sliding friction, static friction is also detected when moving the liner downhole. Repetitive decreases in the linear hook load values, indicate that the pipe string has stopped moving due to static friction. This is followed by a sudden hook load increase as it overcomes the static friction, which leads to a sudden sliding (dynamic friction) of the string.

Hence, dynamic friction can be located at the upper region of the data points and static friction at the lower region of data points. The data points in between, result from the linear-elastic behaviour of the pipe string during adhesion (Young's modulus). However, the spreading of the pattern varies in intensity from operation to operation.

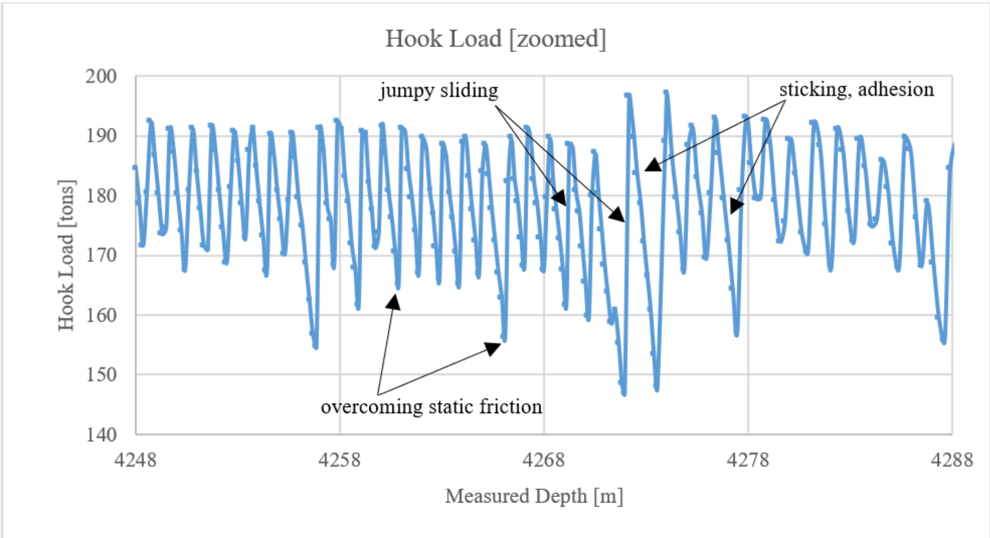

Figure 6: Static and dynamic friction changes

4.2 Detailed Section Analysis

In the detailed section analysis, the following key parameter cross plots are displayed:

- Hook load progression during liner installation incl. flow rate and revolutions per minute (RPM) vs. measured depth.
- Hook load progression during the last check trip when running in hole with DP before liner installation incl. flow rate and revolutions per minute (RPM) vs. measured depth.

- Δ Hook load and running speed vs. measured depth.
- Δ Hook load and inclination vs. measured depth.
- Δ Hook load and azimuth vs. measured depth.
- Δ Hook load and DLS vs. measured depth.

Figure 7 shows an example of a detailed section analysis. The first two plots at the top show the hook load progression of the liner installation and the hook load progression of the last check trip before running the liner over running depth. Subsequent plots show the Δ hook load development which is the first derivative of the hook load progress to the average hook load at a certain depth. It is used as an indicator for hook load pattern development. The influence of dog leg severity (DLS), inclination, azimuth and running speed on Δ hook load development over running time is analysed with cross plotting the individual parameters against each other.

4.3 Comparison Analysis

In the comparison analysis, the opportunity to plot several crucial framework parameters of different selected wells for evaluation is provided:

- Inclination vs. measured depth.
- Azimuth vs. measured depth.
- DLS vs measured depth.
- Friction coefficients vs. measured depth.
- Different mud weights of the wells.
- Overall hook load progression.

Figure 8 shows an example of the comparison analysis of three different wells.

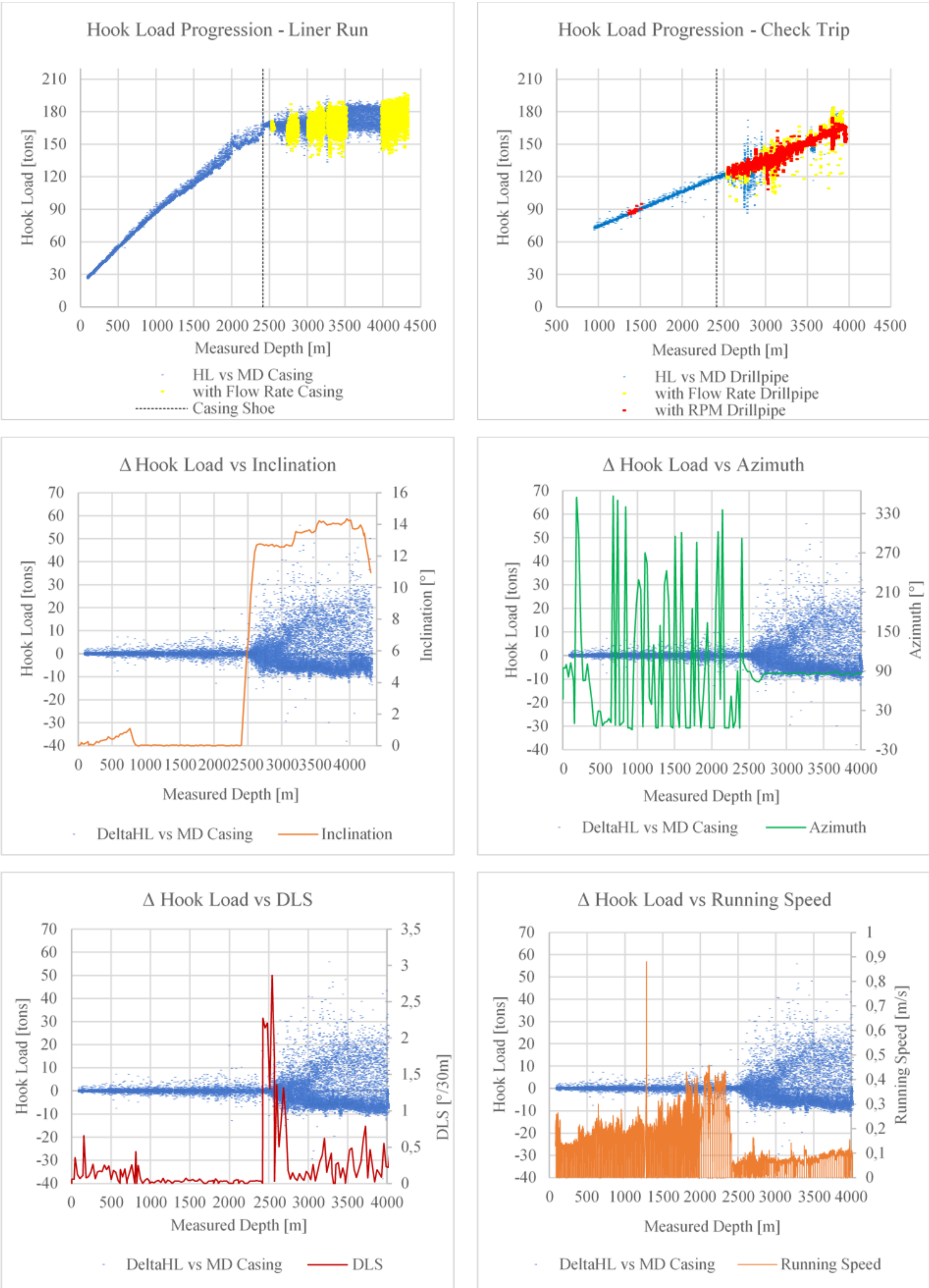

Figure 7: Example of a detailed section analysis

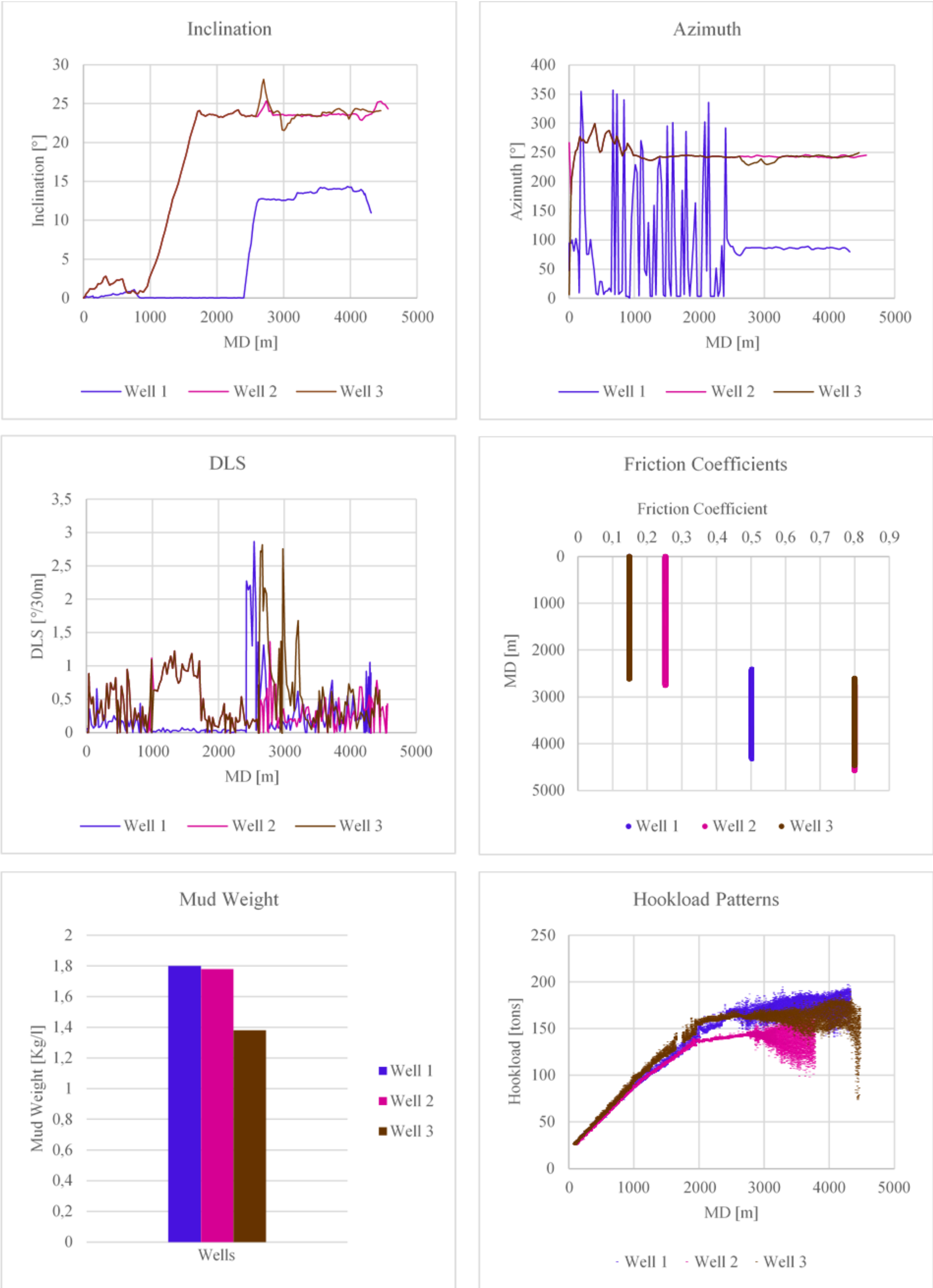

Figure 8: Example of a comparative analysis of three running liner operations

5. CONCLUSION

The analysis of a broad spectrum of well parameters shows, that the reasons for single hook load deviations in a well can vary from case to case. However, similarities in hook load progression behaviour between different wells can be observed. An important parameter is the first derivative of the hook load progress, referred to as "Δ hook load". The Δ hook load is used as an indicator for hook load pattern development. Smooth liner installations typically show rather small and constant Δ hook load values over the whole running depth. Challenging liner installations are typically characterised by increased Δ hook load values over running depth. The influence of dog leg severity, inclination, azimuth and running speed on Δ hook load development over running time, is analysed by cross plotting the individual parameters against each other. Different causes for the changes in Δ hook load can be identified for different wells.

The following, newly developed workflow helps to minimise risk during casing running:

1. Simulation of a set of predefined friction coefficients.
2. Calibration of the friction model with real time hook load data during operation.
3. Continuous monitoring of hook load development versus running depth comparing the initial model value to the actual hook load values.
4. Evaluation of the real time data in the analysis portal, keeping an eye on Δ hook load.
5. Identification of individual hook load development influencing parameters and comparison of hook load development with nearby reference wells.
6. Identification of critical hook load patterns at an early stage before the operation gets critical and reassessment of the situation.

If a liner or casing is to be run, an additional recommended step is to take a closer look at the hook load progression of the last check trip before running the liner. Running in hole of the last check trip should be conducted without circulation or rotation of the drill pipe to reproduce similar conditions to the liner running job. When implemented in the database and plotted against running depth, affinities in hook load deviations from the drill pipe run to the liner run can be observed, as demonstrated in Figure 7. If severe anomalies in hook load progression are observed during the last check trip, further well conditioning actions (prior to running the liner) should be discussed.

In order to improve the process of assessing the situation in case of any irregularities, stop criterions for the casing/liner running job should be defined and clearly stated before running the liner in hole. The following "traffic light system" is currently being developed, in order to support decision making:

Green light (ok): According to the simulation, the actual real time hook load data follows the calibrated nominal hook load values.

Yellow light (attention): Deviations from the norm have been observed and the actual real time hook load data has deviated from the nominal hook load vales over a certain amount of running time. A new assessment of the situation is required. Measures to decrease friction should be taken (e.g. start circulation)

Red light (stop): Actual hook load values have reached stop criterions. The running job should be interrupted to avoid stuck casing. A new assessment of the situation is required before a decision is made to continue running in hole. Measures to decrease friction should be taken or the casing/liner should be pulled out of hole.

The process of defining reliable stop criterions is the biggest challenge. Due to the financial consequences, the decision to pull a casing/liner is not easy to make. However, precisely for this reason, objective criterions must be identified in future studies.

REFERENCES

C.A. Johancsik, D.B. Friesen, Rapier, Dawson: Torque and Drag in Directional Wells – Prediction and Measurement. In: *SPE 11380,* (1984)

Flechtner, F., Aubele, K.: A brief stock take of the deep geothermal projects in Bavaria, Germany, *Proceedings - 44th Workshop on Geothermal Reservoir Engineering,* Stanford University, Stanford, California (2019).

Robert F. Mitchell and Robello Samuel, Haliburton DE&DS: How Good is the Torque and Drag Model? In: *SPE/IADC 105068,* (2007)