

# A Python-based modeling enabling lithology-driven friction factor calibration

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## Abstract

**Purpose.** The purpose of this paper is to develop and validate a Python-based workflow for processing continuous hook-load data and applying it to lithology-driven friction-factor calibration in torque-and-drag analysis during casing-running operations in deep, high-pressure wells.

**Methods.** The proposed workflow is based on the automated processing of continuous mud-logging hook-load data recorded during casing deployment. The procedure includes data cleaning, threshold-based segmentation, rolling filtering, outlier removal, and extraction of representative tripping-in and tripping-out load trends. The processed trends are then compared with field measurements and used to calibrate interval-specific friction factors in torque and drag simulations for two offshore wells.

**Findings.** The results show that the developed workflow converts noisy continuous hook-load records into stable load trends suitable for calibration. In both analyzed wells, a single constant friction factor was insufficient to reproduce the full mechanical response of the casing run. Better agreement was achieved when friction factors were calibrated for individual depth intervals. The calibrated profiles also showed that changes in friction behavior were generally consistent with lithological transitions and heterogeneous wellbore conditions.

**Originality.** The study's originality lies in combining continuous mud-logging hook-load data, automated Python-based processing, and interval-specific torque- and drag-calibration into a single workflow for lithology-sensitive interpretation of casing-running behavior.

**Practical implications.** The proposed approach reduces reliance on manual point selection, improves the consistency of post-run torque-and-drag calibration, and can serve as a practical engineering tool for analyzing casing-running performance in geologically complex wells.

**Keywords:** *torque and drag analysis; friction factor calibration; casing-running operations; mud-logging data; lithology; Python workflow; wellbore mechanics*

## 1. Introduction

Running long, heavy casing strings in deep directional wells remains one of the most mechanically demanding stages of well construction. The risk of excessive drag, inability to reach target depth, local overloading of the string, and poor casing placement increases when long open-hole intervals, complex trajectories, and unstable formation conditions are combined within a single section. For this reason, torque and drag analysis have long been used as a primary engineering tool for evaluating the mechanical feasibility of casing-running operations and predicting axial load behavior under downhole contact conditions [1], [2].

At the same time, the practical reliability of torque and drag analysis depends not only on the model's mathematical structure but also on the quality of the input assumptions used during calibration. One of the most uncertain parameters in this context is the friction factor. Earlier studies showed that even when the general mechanics of string movement are adequately represented, the model's predictive

capability may still be limited by uncertainty in borehole geometry, contact conditions, trajectory representation, and friction-factor selection [3]-[5]. In routine practice, friction factors are often selected based on offset experience, sensitivity ranges, or simplified assumptions for long well sections. Such an approach may be sufficient at the planning stage, but it becomes less reliable when the objective is detailed post-run diagnosis or field-based calibration.

This limitation is particularly important in wells drilled through geologically heterogeneous intervals. Changes in lithology may affect wellbore condition, wall roughness, mud-cake quality, contact response, and local resistance during casing movement. As a result, the friction factor cannot always be treated as a constant over the entire open-hole section. However, in many field applications, torque and drag calibration still relies on a limited number of manually selected pick-up and slack-off points rather than the full continuous hook-load record. This reduces repeatability and may obscure interval-specific changes in mechanical response [6], [7].

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Recent work in drilling engineering has increasingly focused on automated interpretation, real-time monitoring, and the integration of field data streams into torque-and-drag workflows [8], [9]. These studies showed that digital methods can improve the speed and consistency of engineering analysis, especially in wells with large volumes of operational data. At the same time, they showed that the value of such methods depends on how reliably raw field measurements can be transformed into interpretable trends suitable for calibration and decision support. This is particularly relevant for casing-running operations, where borehole quality, local geometry, and drag-related risks directly affect the string's ability to reach target depth [10].

A further difficulty concerns the use of continuous mud-logging hook-load data. Although such data are routinely recorded during casing deployment, they often contain operational noise, short-term disturbances, non-representative intervals, and sensor-related scatter. Direct use of the raw signal is therefore problematic. In practice, engineers often exclude part of the data, select only a few representative points, or apply simplified interpretation rules. As a result, the calibration process becomes more subjective and less reproducible. Under these conditions, obtaining an interval-specific interpretation of friction behavior is difficult, even though such an interpretation may be necessary in wells with variable geological and mechanical conditions.

This issue is particularly relevant for deep offshore wells in the South Caspian region, where high pressures, narrow operational margins, long casing strings, and structurally complex intervals create challenging conditions for drilling and casing-running operations [11]. Field experience from this region has already demonstrated the technical complexity of running long 13 3/8 in. casing strings and the importance of accurate planning for pore pressure, mud weight, zonal isolation, and well design [12]. However, the available case-based literature still provides limited methodological detail on how continuous hook-load data can be processed and used to calibrate interval-specific friction factors while preserving both mechanical meaning and geological context.

The present study addresses this gap by developing a Python-based workflow to process continuous hook-load data and calibrate friction factors for torque and drag analysis during casing-running operations, guided by lithology. The workflow was tested on two offshore case wells. The study focuses on extracting representative tripping-in and tripping-out trends from noisy field data, comparing the processed trends with field observations and model outputs, calibrating friction factors for selected depth intervals, and interpreting the calibrated values in relation to lithological changes and wellbore heterogeneity.

## 2. Materials and methods

### 2.1. Study context and analyzed wells

The study focused on two offshore wells drilled in the South Caspian region under deep, high-pressure conditions. Both wells included a 13 3/8 in. casing-running operation through a mechanically demanding interval with long open-hole exposure, complex geology, and elevated operational risk. The analyzed section was selected because it represented the most critical part of the casing run in terms of drag behavior, uncertainty in friction-factor selection, and sensitivity

to local wellbore conditions. Previous field experience in the same regional setting has shown that long casing strings in this interval require careful planning for mud weight, pore pressure, casing design, and zonal isolation [11].

A typical well architecture and casing program for the field under study is presented in Figure 1.

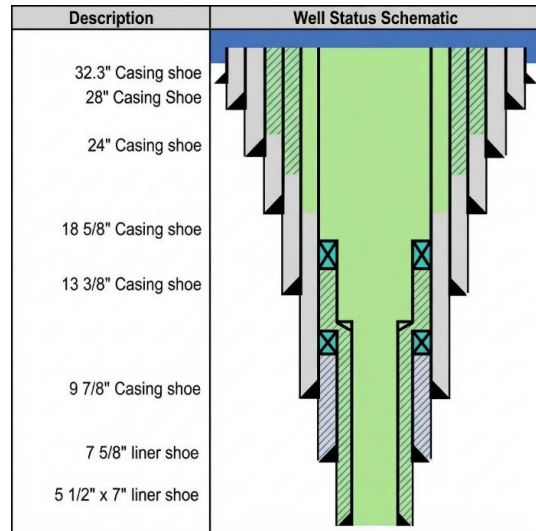


Figure 1. Schematic representation of the well architecture and casing program for the analyzed field

The analyzed interval corresponds to the 14 3/4 in. × 17 1/2 in. section, in which the 13 3/8 in. casing string is run through a long open-hole interval below the previous casing shoe.

In this field, the 14 3/4 in. × 17 1/2 in. hole is typically drilled with a 2.00-2.15 sg non-aqueous-based mud (NABM) to run the 13 3/8 in. casing string to approximately 5000 m MD [12]. The primary purpose of the 13 3/8 in. casing string is to isolate the high-pressure Surakhany, Sabunchy, and shaly Balakhany intervals, thereby enabling safe drilling into the deeper depleted formations [13]. The previous 18 5/8 in. casing string was set within the 2200-2500 m MD range to isolate reactive and swelling shales in the overburden and to provide sufficient shoe strength for drilling the next section. This design is important because the wells in the analyzed field follow a J-type trajectory and include a long open-hole interval below the previous shoe, which increases the mechanical complexity of casing-running operations.

The primary geological and operational conditions of the analyzed interval are summarized in Table 1.

The stratigraphic framework and lithology-based interpretation of the analyzed section are presented in Figure 2. This figure shows the relative positions of the main intervals penetrated in the 14 3/4 in. × 17 1/2 in. section and provides geological context for the subsequent interpretation of depth-dependent friction-factor changes.

For clarity, the principal lithostratigraphic intervals interpreted from the section schematic are summarized in Table 2. The tabular format is intended to make stratigraphic relationships more explicit and to provide a clearer basis for interpreting changes in calibrated friction factor with depth.

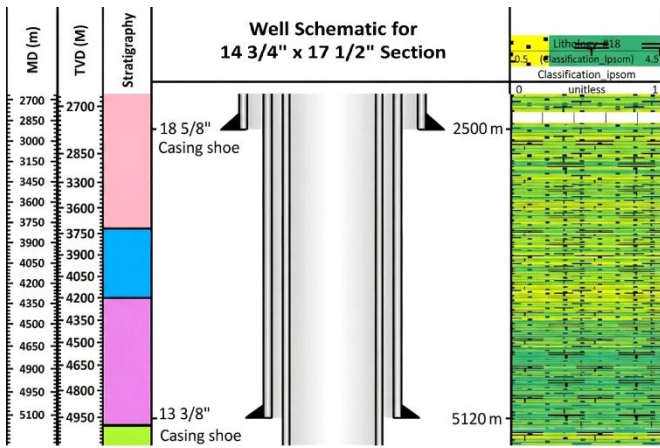
The inclination profiles of the two wells analyzed are shown in Figure 3. Although both wells were drilled within the same general field setting, their trajectories were not identical, and these differences were accounted for in subsequent torque and drag analysis and friction-factor calibration.

**Table 1. Summary of geological and operational conditions for the 14 3/4 in. × 17 1/2 in. hole section (13 3/8 in. casing string)**

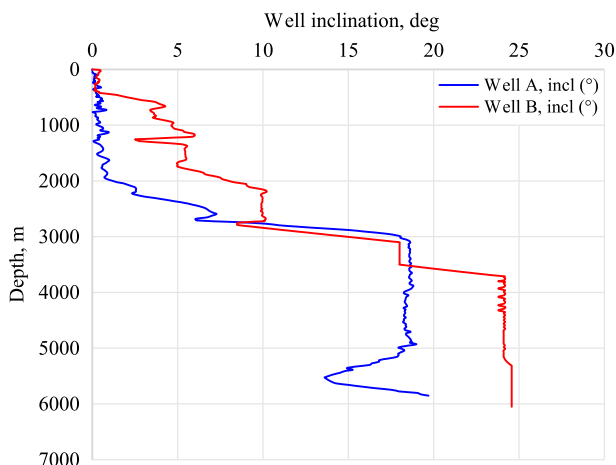
Parameter	Description
Previous casing	2200-2500 m MD
Casing shoe depth	4900-5100 m MD
Total depth criteria	30 m above the top of the Balakhany V formation, accounting for depth uncertainty; isolation of the high-pressure Surakhany, Sabunchy, and shaly Balakhany intervals
Drilling fluid	2.00-2.15 sg non-aqueous based mud (NABM)
Geological hazards and risks	Fault crossing at approximately 4500 m; expected water and gas influx; risks of wellbore collapse, tight hole, and losses; overpull, slack-off, and multiple stuck-pipe events reported in the previous two wells
Cementing objective	Safe and efficient operations; provision of a competent shoe for drilling the next 12 1/4 in. section; successful formation integrity test (FIT)

**Table 2. Lithostratigraphic intervals of the analyzed 14 3/4 in. × 17 1/2 in. section**

Formation / interval	Top, m MD	Bottom, m MD	Thickness, m	General lithological character	Relevance to friction-factor interpretation
Surakhany	2500	3750	1250	Predominantly sandy-shaly interval	Upper high-pressure interval requiring separate friction-factor interpretation
Sabunchy	3750	4300	550	Mixed clastic interval	An intermediate interval is associated with a distinct change in friction behavior
Shaly Balakhany / Top Balakhany	4300	5100	800	More shale-rich interval	Lower interval characterized by a distinct friction-factor response
Lower-most part of the analyzed section	5100	5120	20	Lower boundary marker of the analyzed section	Section-bottom reference associated with the 13 3/8 in. casing shoe



**Figure 2. Stratigraphic framework and lithology-based representation of the analyzed 14 3/4 in. × 17 1/2 in. section**



**Figure 3. Inclination profiles of Well A and Well B as a function of measured depth**

**2.2. Input data**

The input dataset used in this study consisted of continuous hook-load measurements recorded during casing-running operations, along with the corresponding depth record and

field observations collected during the run. In addition to the continuous mud-logging data, discrete pick-up and slack-off measurements taken by the rig crew were used for validation and interpretation. Well trajectory data, casing design parameters, and lithostratigraphic interval information were also incorporated into the workflow to support torque and drag analysis and interval-specific calibration.

Continuous hook-load and depth data were exported from the rig mud-logging system at a 10 s recording interval and referenced to measured depth.

Continuous hook-load data were treated as the primary diagnostic signal because they directly reflect the casing string’s axial response during movement in the wellbore. However, in raw form, this signal usually contains operational interruptions, sensor noise, local spikes, and short-term disturbances that are not representative of actual downhole mechanical behavior. For that reason, the raw signal was not used directly for calibration. Instead, it was processed to extract representative tripping-in and tripping-out trends suitable for comparison with model outputs.

Trajectory data were used to define the geometric path of each well and to provide the basis for axial load calculations in the torque-and-drag model. Casing design data were used to describe the mechanical characteristics of the string during the analyzed run. Lithostratigraphic information was incorporated as an interpretive layer to determine whether changes in calibrated friction behavior were consistent with formation boundaries and expected changes in wellbore condition. In this way, the dataset combined operational measurements, well geometry, string design, and geological context within a single calibration workflow.

**2.3. Python-based hook-load processing workflow**

A Python-based workflow was developed to transform the continuous hook-load record into a calibration-ready dataset. The workflow was designed as a post-run analytical sequence that links raw operational data to interval-specific friction-factor interpretation. The workflow’s general logic is shown in Figure 4.

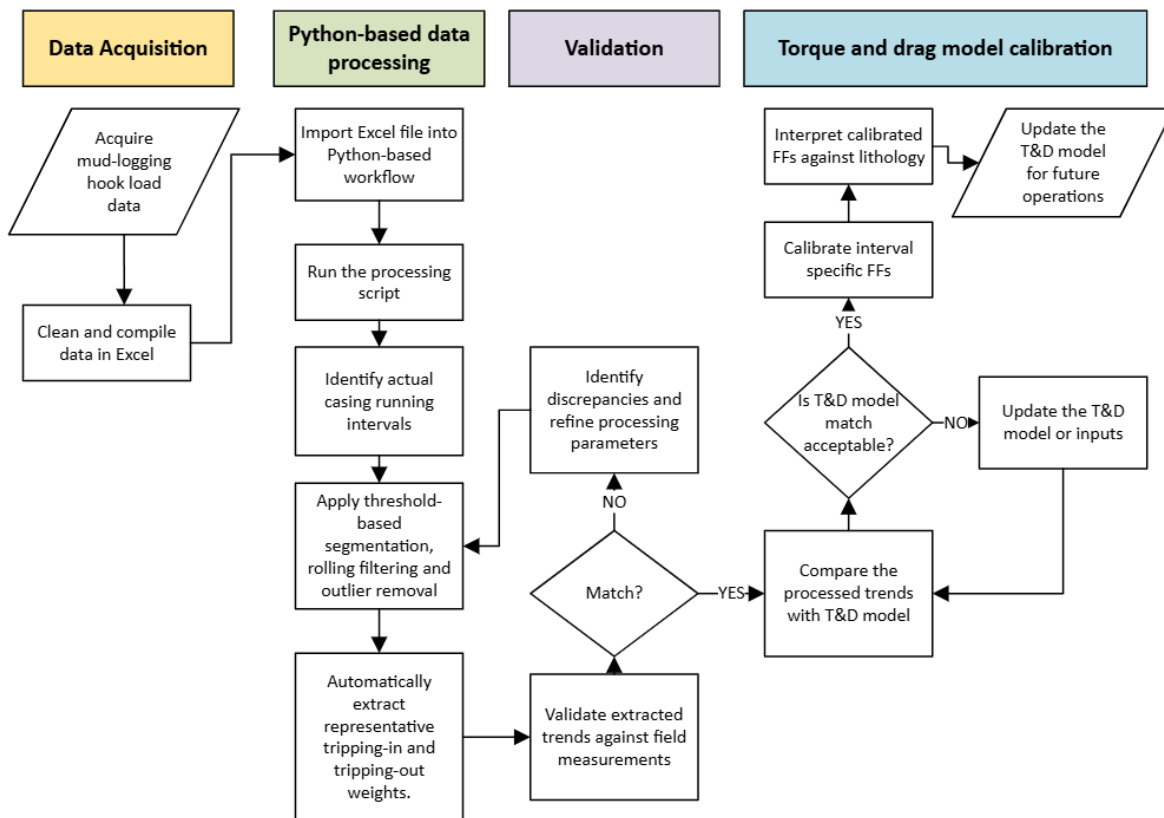


Figure 4. Flowchart of the proposed Python-based workflow for hook-load data processing and friction-factor calibration

The data-processing workflow was implemented in Python using standard analytical libraries, whereas torque-and-drag simulations were performed in WellPlan. Intervals corresponding to actual casing movement were identified from the depth record and the continuity of the hook-load response; records associated with static periods, slips, and other non-running operations were removed from the dataset before further processing. The signal was then smoothed with a five-sample rolling window, and anomalous values were excluded using a Z-score threshold of 3.0. Representative tripping-in and tripping-out envelopes were subsequently extracted over 12 m depth intervals and used for validation and friction-factor calibration.

The first stage of the workflow involved collecting available mud-logging and operational data for the casing-running interval under analysis. These data were then cleaned and organized into a structured format suitable for further processing. At this stage, clearly non-informative or corrupted parts of the record were excluded to improve data consistency.

The second stage involved identifying intervals of actual pipe movement and separating them from periods of rig inactivity, operational pauses, or irregular surface events. This step was necessary because the continuous field record contains many segments that do not represent stable casing movement and should therefore not be used directly for mechanical interpretation.

The third stage involved signal processing. Threshold-based segmentation, rolling filtering, and outlier removal were applied to suppress local fluctuations while preserving the underlying depth-dependent trend. This reduced the influence of isolated spikes and short-lived anomalies that were not representative of the casing string’s actual frictional response.

The next stage was to extract representative tripping-in and tripping-out trends from the processed dataset. These extracted envelopes were treated as the primary field-based response curves for calibration. Their purpose was to provide a clearer, more repeatable representation of hook-load behavior than the original unsorted data cloud.

The following stage involved validating the processed trends against field observations. At this stage, the extracted responses were compared with measured values recorded during operations. The purpose of this step was to ensure that the processed envelopes preserved the physical meaning of the field response and could be used with sufficient confidence in the next stage of modeling.

The final stage compared the processed field response with torque-and-drag model outputs under different friction-factor assumptions. This structure aligns with the general direction of recent drilling studies, which have increasingly focused on automated interpretation, digital torque-and-drag workflows, and the integration of field data into engineering analysis [14].

#### 2.4. Torque and drag modeling basis

Torque and drag analysis served as the physical framework for interpreting the processed hook-load data in this study. Classical torque and drag approaches describe the axial response of a tubular string moving through a curved wellbore under the combined influence of string weight, buoyancy, normal contact force, and friction [15]. In practical applications, the reliability of this analysis depends strongly on the assumed friction factor and on how well the model reflects actual well geometry and field conditions [16].

In this study, the model was used to simulate hook-load behavior during tripping-in and tripping-out for the 13 3/8 in.

casing string. The initial analysis included multiple friction-factor sensitivity cases to assess how well a single constant value could reproduce the field response over the full interval. This step provided an initial estimate of the general range of friction behavior in each well.

However, the study's purpose was not limited to global sensitivity analysis. The main objective was to determine whether the friction response remained uniform with depth or varied across intervals (or lithologies). For this reason, the model was subsequently used to calibrate the interval-specific friction factor. Separate friction-factor values were considered for selected geological intervals and for tripping-in and tripping-out conditions.

## 2.5. Calibration procedure

The calibration procedure compared the processed hook-load trends with the modeled torque and drag responses. Calibration was performed progressively rather than through a single global fit. First, the full interval was analyzed using a set of constant-friction-factor scenarios to determine whether a single value could reproduce the measured trend. After that, the section was subdivided into intervals based on the behavior of the processed load curves and geological segmentation.

For each interval, the friction factor was adjusted until the simulated tripping-in and tripping-out responses matched the extracted field trends. The calibration criterion was not a strict point-by-point match. Instead, priority was given to reproducing the field response's overall depth-dependent behavior within a practical range. This approach was adopted because field data inevitably contain operational variability that cannot be eliminated even after processing.

Special attention was given to distinguishing between cased-hole and open-hole sections, as well as to the main formations within the analyzed interval. This enabled comparison of friction behavior not only between the two wells but also across intervals with different geological characteristics.

## 2.6. Validation and comparative analysis

Validation of the extraction workflow was conducted by comparing the processed tripping-in and tripping-out trends with field measurements. For this purpose, both local depth-based error behavior and summary statistics were considered. The validation stage was intended to confirm that the extracted envelopes provided a sufficiently accurate representation of the observed field response for torque and drag calibration. Validation was performed against 8 independent pick-up and slack-off measurements recorded by the rig crew, and extracted values were matched to field checkpoints using the nearest depth interval.

MAPE, RMSE, and  $R^2$  were computed separately for the tripping-in and tripping-out series to quantify extraction accuracy before interval-specific friction-factor calibration.

The same methodological sequence was then applied to both wells analyzed: preparation of the field dataset, signal processing, extraction of representative load trends, torque and drag analysis under multiple friction-factor assumptions, and interval-specific calibration. This comparative approach enabled evaluation of whether the workflow remained applicable across two wells in the same general field setting and whether the resulting friction-factor profiles exhibited recurring or well-specific behavior.

From an engineering perspective, the workflow was considered successful if it met three conditions. First, it had to

convert noisy continuous hook-load records into stable tripping-in and tripping-out trends. Second, it had to improve agreement between field-derived responses and modeled torque and drag behavior. Third, it had to provide a basis for interval-specific interpretation of friction behavior in relation to lithologic and wellbore heterogeneity.

## 3. Results

### 3.1. General response of the processed hook-load data

Application of the developed workflow showed that the raw continuous hook-load record could not be used directly for friction-factor calibration without prior processing. In both wells, the original signal contained short-term fluctuations, isolated spikes, operational interruptions, and non-representative intervals associated with irregular rig activity. These features complicated direct interpretation and made it difficult to distinguish the actual downhole mechanical response from surface-related variability.

After cleaning, filtering, and extraction, the hook-load record became significantly more interpretable. The processed data enabled the identification of stable tripping-in and tripping-out trends and the suppression of the portion of the signal with no clear diagnostic value for torque and drag analysis. This was important not only for improving visual clarity but also for reducing reliance on manually selected calibration points. As a result, the extracted curves provided a more reliable basis for comparing field response with modeled behavior.

A general observation from both wells is that the mechanical response was not uniform across the entire analyzed interval. Instead, the processed trends showed depth-dependent changes, indicating that a single constant friction factor could not adequately represent the entire casing-running section. This observation formed the basis for the interval-specific calibration presented below.

### 3.2. Application of the workflow to Well A

For Well A, the raw hook-load record showed substantial scatter and several non-representative fragments, reflecting operational variability during the casing run. Therefore, the first task was to extract representative tripping-in and tripping-out trends from the continuous dataset before any comparison with torque and drag outputs was attempted.

The extracted trends shown in Figure 5 provide a clearer representation of the field response than the original unsorted data cloud. They preserve the main depth-dependent behavior of the casing-running loads while suppressing local scatter and isolated irregularities. These processed envelopes were then used as the basis for subsequent modeling.

The reliability of the extracted trends was evaluated using a depth-based percentage-error analysis. The validation profile for Well A is shown in Figure 6.

The error profile confirms that the extracted tripping-in and tripping-out trends remain within a limited range of deviation over the analyzed interval and therefore retain the physical meaning of the field response. The summary statistics are presented in Table 3.

The values in Table 3 show strong consistency between the extracted load trends and the measured field response. The close agreement in both movement directions confirms that the processing workflow produces calibration-ready input data that are sufficiently accurate for engineering analysis.

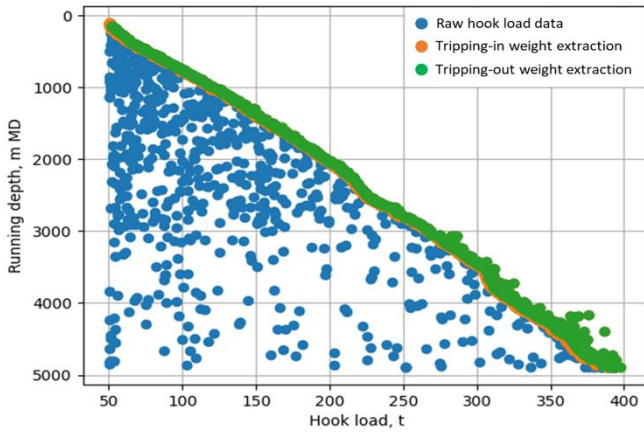


Figure 5. Well A – extraction of representative tripping-in and tripping-out hook-load trends from the raw continuous dataset for the 13 3/8 in. casing run

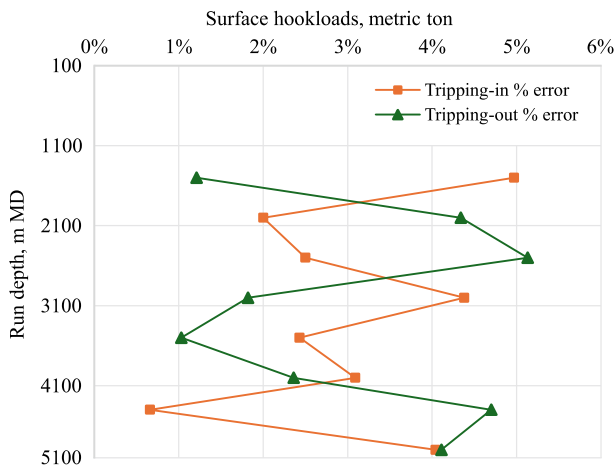


Figure 6. Well A – depth-based validation profile for extracted tripping-in and tripping-out loads expressed as percentage error (MAPE)

Table 3. Summary validation metrics for the extracted pick-up and slack-off trends in Well A

Series	MAPE, %	RMSE, t	R <sup>2</sup>
Slack-off	3.00	8.31	0.993
Pick-up	2.99	10.10	0.991

After validating the extracted curves, the processed field response was compared with torque and drag model outputs generated across multiple friction-factor sensitivity cases. The purpose of this stage was to assess whether a single, constant friction factor could reproduce the full behavior of the casing-running response.

Figure 7 shows that the model curves capture the general trend of the load response, but their agreement with the field-derived tripping-in and tripping-out behavior varies with depth. In some parts of the interval, one friction-factor scenario provides a reasonable approximation. In contrast, in other parts, a different friction response is required to maintain agreement with the observed measurements. This indicates that a single constant friction factor is insufficient for the full section and that calibration should be performed on an interval-specific basis.

The resulting calibrated friction-factor behavior for Well A is shown in Figure 8.

The calibrated friction-factor profile does not remain constant across the analyzed interval. Several depth ranges show relatively stable values, followed by intervals where a noticeable change in friction response is required. The difference between tripping-in and tripping-out friction factors is also preserved, indicating asymmetric mechanical behavior during casing movement. This behavior is consistent with the idea that local contact conditions vary with depth and cannot be represented by a single global friction factor [10].

The interval-specific calibrated values for Well A are summarized in Table 4.

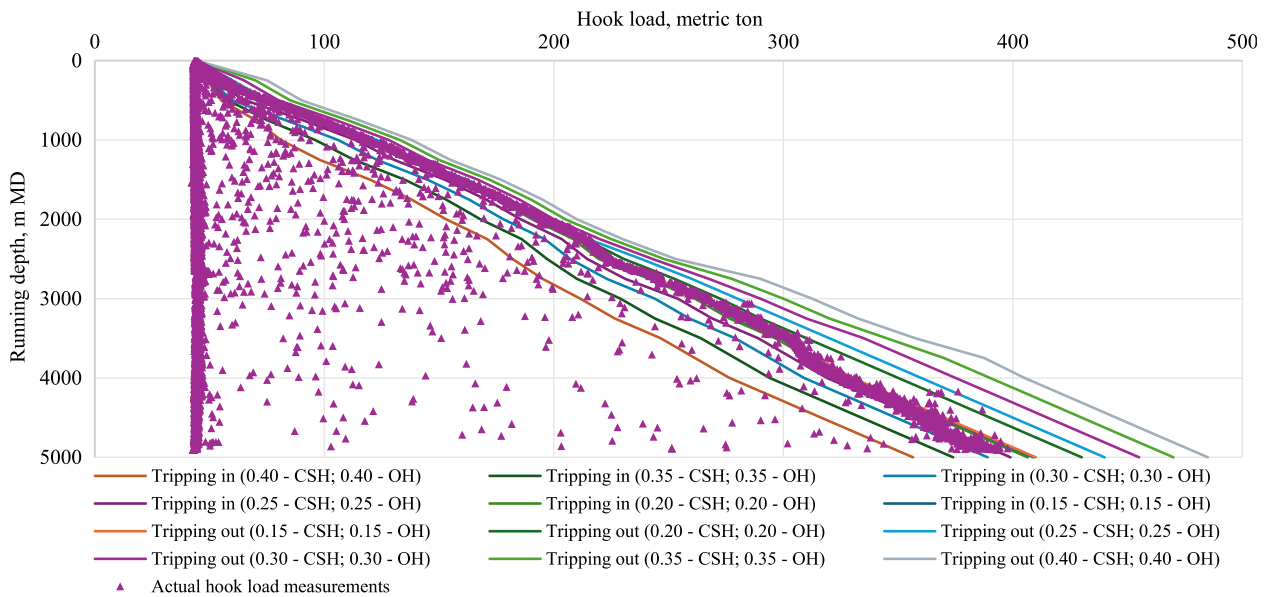


Figure 7. Well A – comparison of torque and drag model responses across multiple friction-factor sensitivity cases, using continuous hook-load measurements and discrete field pick-up / slack-off data

The calibrated values confirm that friction response varies not only between cased- and open-hole sections but also among individual geological intervals. In particular, the

Surakhany and Sabunchy intervals required different friction factors, whereas the top Balakhany interval exhibited a narrow tripping-in range rather than a single fixed value.

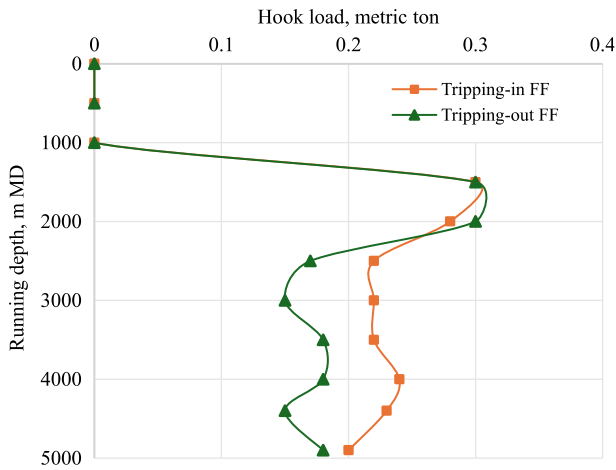


Figure 8. Well A – variation of calibrated friction-factor values with measured depth for tripping-in and tripping-out

Table 4. Interval-specific friction factors calibrated for tripping-in and tripping-out in Well A

Interval	Tripping-in friction factor	Tripping-out friction factor
Cased hole	0.30	0.30
Surakhany	0.15	0.22
Sabunchy	0.20	0.25
Top Balakhany	0.15-0.20	0.20

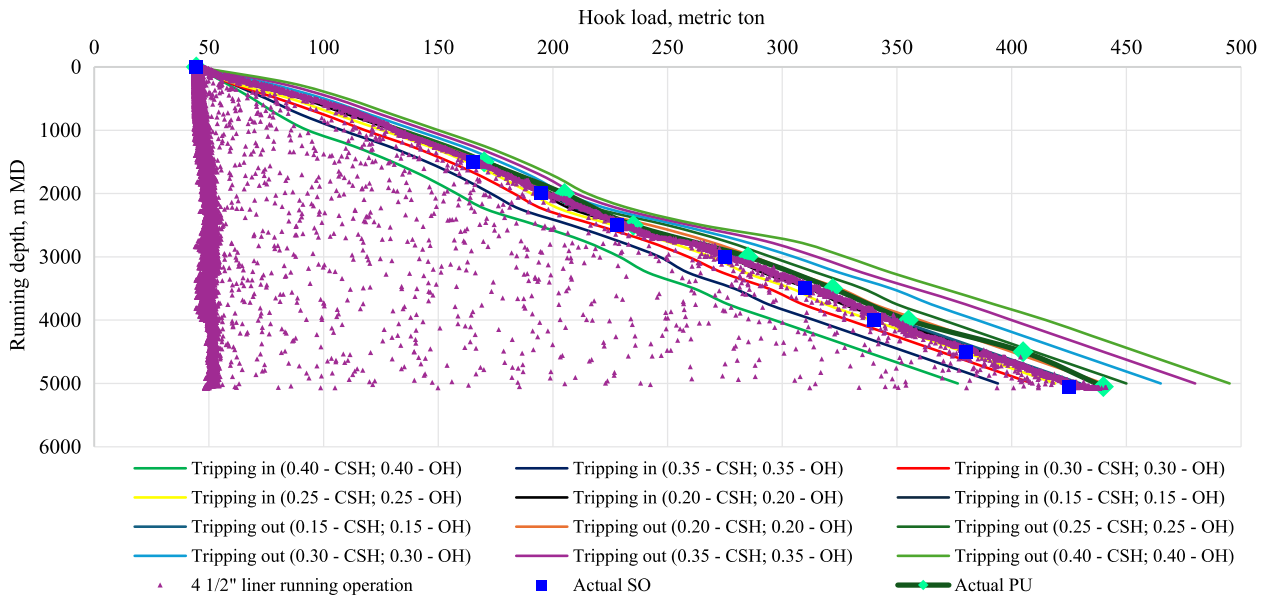


Figure 9. Well B – comparison of torque and drag model responses across multiple friction-factor sensitivity cases, using continuous hook-load measurements and discrete field pick-up/slack-off data

The depth-dependent friction factor profile for Well B appears in Figure 10. Figure shows that the friction response in Well B also varies across the analyzed interval. Some depth ranges exhibit relatively stable calibrated values, whereas others require distinct shifts in friction behavior. The difference between tripping-in and tripping-out friction factors is preserved here as well, confirming that the directional asymmetry of casing movement observed in Well A is not an isolated feature of a single well.

Although the exact friction-factor distribution differs from that in Well A, the second case still supports the same general conclusion: the full interval cannot be adequately represented by a single friction-factor value. Instead, the

This supports the interpretation that friction behavior during casing running is influenced by interval-specific wellbore conditions and lithologic variability rather than by a uniform mechanical regime.

### 3.3. Application of the workflow to Well B

The same workflow was applied to Well B to test whether the methodological logic developed for the first case remained valid for another well trajectory within the same general field setting. As with Well A, the raw continuous hook-load data contained operational scatter and non-representative fragments that required preprocessing before comparison with model outputs.

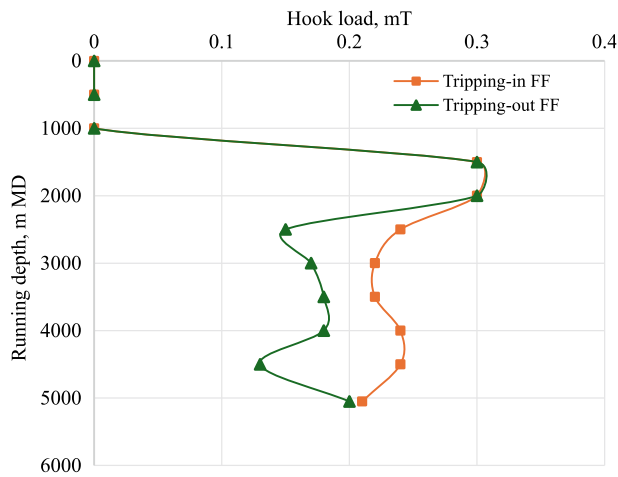
After applying the same extraction and calibration sequence, the processed field response for Well B was compared with torque-and-drag model outputs across a range of friction-factor sensitivity cases. The results are shown in Figure 9.

The comparison in Figure 9 shows the same general tendency as in Well A. The model reproduces the overall depth-dependent trend of the casing-running response, but the match quality varies across the interval. No single constant-friction-factor scenario provides equally good agreement across the full section. This again indicates that the mechanical response changes with depth and that a depth-sensitive calibration strategy is required.

calibration results suggest that casing-string interaction should be interpreted in the context of depth-dependent geological and wellbore conditions.

### 3.4. Comparative discussion of Wells A and B

The comparison of the two analyzed wells shows that the proposed workflow delivered consistent methodological benefits in both cases. In each well, the raw continuous hook-load record contained useful mechanical information, but noise, irregular events, and operational scatter initially obscured it. After processing, both datasets produced more stable tripping-in and tripping-out trends suitable for comparison with torque and drag outputs.



**Figure 10. Well B – variation of calibrated friction-factor values with measured depth for tripping-in and tripping-out**

The first key finding is that a single friction factor was insufficient to capture the full casing-running response in either well. In both cases, global sensitivity analysis captured the general trend only partially, whereas interval-specific calibration yielded a more realistic match between modeled and field-derived behavior. This aligns with previous studies that identified friction-factor uncertainty as a major limitation of conventional torque-and-drag interpretation [2], [5], [8].

The second common result is that the calibrated friction response was depth- and direction-dependent in both wells. The tripping-in and tripping-out friction factors did not coincide, and the locations of the main friction shifts were not randomly distributed along the interval. Instead, they were associated with changes in local mechanical response that can be interpreted in relation to lithological segmentation and wellbore heterogeneity. This behavior aligns with the broader trend reported in recent digital and automated torque-and-drag studies, where field data are increasingly used not only for global matching but also for more detailed operational interpretation [9], [16].

At the same time, the two wells were not identical. Their trajectories and friction-factor profiles differed. This is an important result in itself because it shows that the workflow should not be used to transfer a single fixed friction template from one well to another. Its value lies in providing a reproducible procedure for extracting the mechanical signature of each casing-running operation from continuous field data and interpreting that signature within its own geological and operational context.

From a practical standpoint, the proposed workflow offers three advantages. First, it reduces reliance on manual selection of isolated calibration points. Second, it improves the consistency of model interpretation by using continuous processed trends rather than sparse observations. Third, it enables identification of specific intervals where the mechanical response deviates from the average behavior, thereby requiring closer attention during post-run analysis and in planning future operations.

#### 4. Conclusions

This study developed and applied a Python-based workflow to process continuous hook-load data and to use the results for friction-factor calibration in torque and drag analysis during casing-running operations. The workflow was tested on two offshore wells drilled in the South Caspian region under deep, high-pressure conditions.

The results showed that raw continuous hook-load data could not be used directly for reliable calibration because the original signal contained operational scatter, short-term disturbances, and non-representative intervals. After cleaning, filtering, and extraction, the processed datasets provided stable tripping-in and tripping-out trends that preserved the main depth-dependent mechanical response of the casing run and were suitable for further analysis.

Validation of the extracted trends for Well A confirmed that the proposed processing procedure provided sufficiently accurate calibration input. The obtained MAPE, RMSE, and  $R^2$  values showed close agreement between the extracted load trends and the measured field response, which supports the practical applicability of the workflow for post-run engineering analysis.

Comparison of the processed field data with torque and drag model outputs showed that a single constant friction factor was insufficient to reproduce the full casing-running response in either well. Better agreement was achieved when calibration was performed for individual depth intervals. The resulting friction-factor profiles showed that the mechanical response varied with depth and that tripping-in and tripping-out behavior remained distinct throughout the analyzed interval.

The calibrated interval-specific friction factors also showed a meaningful relationship with geological segmentation. The most pronounced changes in friction response occurred during intervals where lithologic variation and changes in wellbore condition were expected. At the same time, the results indicate that lithology should not be treated as the sole controlling factor, since borehole quality, local geometry, and operational conditions also affect casing-running behavior.

Comparison of the two wells confirmed that the proposed workflow is applicable beyond a single case. Although the exact friction-factor distributions were not identical, both wells showed the same general pattern: continuous hook-load data, when processed properly, can be used to identify depth- and direction-dependent friction behavior more reliably than sparse manual observations and a single global calibration value.

Overall, the proposed workflow is a practical tool for post-run analysis of casing-running operations in geologically complex wells. It improves the consistency of torque and drag calibration, reduces reliance on manual point selection, and provides a more realistic basis for interval-specific interpretation of casing-string behavior

#### Author contributions

Conceptualization: VI, YSh; Data curation: VI; Formal analysis: GJ, VI, YSh; Investigation: VI, YSh; Methodology: GJ, VI; Project administration: YSh; Resources: GJ, VI, YSh.; Software: VI; Supervision: YSh; Validation: GJ, YSh; Visualization: VI; Writing – original draft: VI; Writing – review & editing: GJ, YSh. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of interests

The authors declare no conflict of interest.

## Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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## Python-моделивання для калібрування коефіцієнта тертя з урахуванням літології

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**Мета.** Метою роботи є розроблення та валідація Python-орієнтованого підходу до оброблення безперервних даних про навантаження на гаку та його застосування для калібрування коефіцієнта тертя з урахуванням літологічної будови під час аналізу сил опору і навантажень у процесі спуску обсадних колон у глибоких свердловинах з високим пластивим тиском.

**Методика.** Запропонований підхід ґрунтується на автоматизованому обробленні безперервних даних геолого-технологічного контролю щодо навантаження на гаку, зареєстрованих під час спуску обсадної колони. Процедура включає очищення даних, сегментацію на основі порогових значень, ковзне фільтрування, видалення викидів, а також виділення репрезентативних трендів навантаження під час спуску та підйому. Отримані тренди далі порівнюються з польовими вимірюваннями та використовуються для калібрування коефіцієнтів тертя за окремими інтервалами в межах моделювання сил тертя і поздовжніх навантажень для двох морських свердловин.

**Результати.** Показано, що розроблений підхід дає змогу перетворювати зашумлені безперервні записи навантаження на гаку у стабільні тренди навантаження, придатні для калібрування. Для обох проаналізованих свердловин встановлено, що використання одного сталого коефіцієнта тертя не забезпечує належного відтворення повної механічної реакції обсадної колони під час спуску. Краща узгодженість досягається за калібрування коефіцієнтів тертя для окремих глибинних інтервалів. Отримані профілі також показали, що зміни характеру тертя загалом узгоджуються з літологічними переходами та неоднорідними умовами стовбура свердловини.

**Наукова новизна.** Поєднання в межах єдиного підходу безперервних даних геолого-технологічного контролю навантаження на гаку, їх автоматизованого оброблення засобами Python і поінтервального калібрування моделі сил тертя та поздовжніх навантажень, що забезпечує літологічно чутливу інтерпретацію поведінки обсадної колони під час спуску.

**Практична значимість.** Запропонований підхід зменшує залежність від ручного вибору окремих точок, підвищує послідовність подальшого калібрування моделей сил тертя і поздовжніх навантажень та може бути використаний як практичний інженерний інструмент для аналізу процесу спуску обсадних колон у геологічно складних умовах.

**Ключові слова:** аналіз сил тертя і поздовжніх навантажень; калібрування коефіцієнта тертя; спуск обсадної колони; дані геолого-технологічного контролю; літологія; Python-підхід; механіка стовбура свердловини

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