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# Concept of a Geothermal Extended Reach Well in Munich

**Maximilian Minihold, Manuel Fasching, Daniel Lackner, David Lentsch, Artjom Baydin und Toni Ledig**
Stadtwerke München

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## 1. Abstract

In order to maximize the potential of deep geothermal energy in Munich, while at the same time reducing the number of drilling sites, development costs and the implementation time of geothermal projects, it is important that individual well sites achieve the highest possible production rates. One evident strategy to enhance the productivity of a drilling site is to expand the development radius around the location as well as the number of boreholes. Wells in the Munich area have been drilled up to 3,000 m horizontal departure (HD), but there is potential for further horizontal reach. However, this requires the outer wells to be drilled at a considerable distance, almost horizontally, from the surface starting point to the landing point. This increasing horizontal distance of the target from the well site inevitably leads to increased technical effort, cost and risk. This paper presents the challenges and limitations arising when applying conventional drilling and liner running methods on wells with extended reach. A thorough risk analysis is provided, detailing the identified limitations. Additionally, various aspects of the well design are highlighted and reviewed.

## 2. Introduction

To optimally utilize the full potential of deep geothermal energy within a specific claim, while simultaneously reducing the number of drilling sites, development costs, and the duration of the geothermal expansion path, it is crucial for individual sites to achieve a high production rate. A straightforward measure to increase the productivity of a drilling site is to increase the development radius around a drilling location and the number of boreholes. To enable this the outer boreholes need to overcome a large horizontal distance between the starting point and the landing point (extended reach drilling).

The term “Extended Reach Drilling (ERD)” was coined in the oil and gas industry and was originally used for boreholes where the ratio between horizontal reach and true vertical depth (TVD) is at least two. Over the years the term has evolved and now also includes boreholes with a ratio of less than two (Hussain et al. 2021). It is much more about the complexity of the well trajectory that arises due to the high reach for specific depths. Therefore, in the Dog Nose plot (Figure 1), different levels of difficulty – “Low Reach”, “Medium Reach”, “Extended Reach”, and “Extreme Reach” – are distinguished.

In the Munich area, horizontal distances between the starting point and endpoint of about 3,120 m have been achieved at shallow depths (around 2,000 m TVD) (see Ismaning Th2 in Figure 1, Lentsch et al. 2015, p. 98). At greater depths of around 4,500 to 5,100 m TVD, horizontal distances up to 2,800 m have been reached (see Holzkirchen Th2b and Sauerlach Th3b in Figure 1, Dorsch et al., 2021). These boreholes are nearly in the transition zone between “Medium Reach” and “Extended Reach”. At intermediate reservoir depths of around 2,700 m TVD, maximum horizontal distances of 3,000 m have been achieved so far (see Schäftlarnstraße Th3 in Figure 1).

However, significantly larger horizontal distances have already been realized in the global drilling industry (Figure 1). Consequently, the potential for increasing the horizontal reach of geothermal wells in the Munich area remains very high. Therefore, as part of a research project (GIGA-M), Stadtwerke München (SWM) plans to design a concept of several exemplary boreholes at various depths with extended reach, where the maximum horizontal distance to the landing point will be at least 6,000 m, thereby roughly doubling the maximum reach achieved in the past. In this paper a “Conceptual Well” reaching the transition zone between “Medium Reach” and “Extended Reach” at a shallower depth of about 2,500 m as illustrated in Figure 1 (green dot), is explicitly addressed.

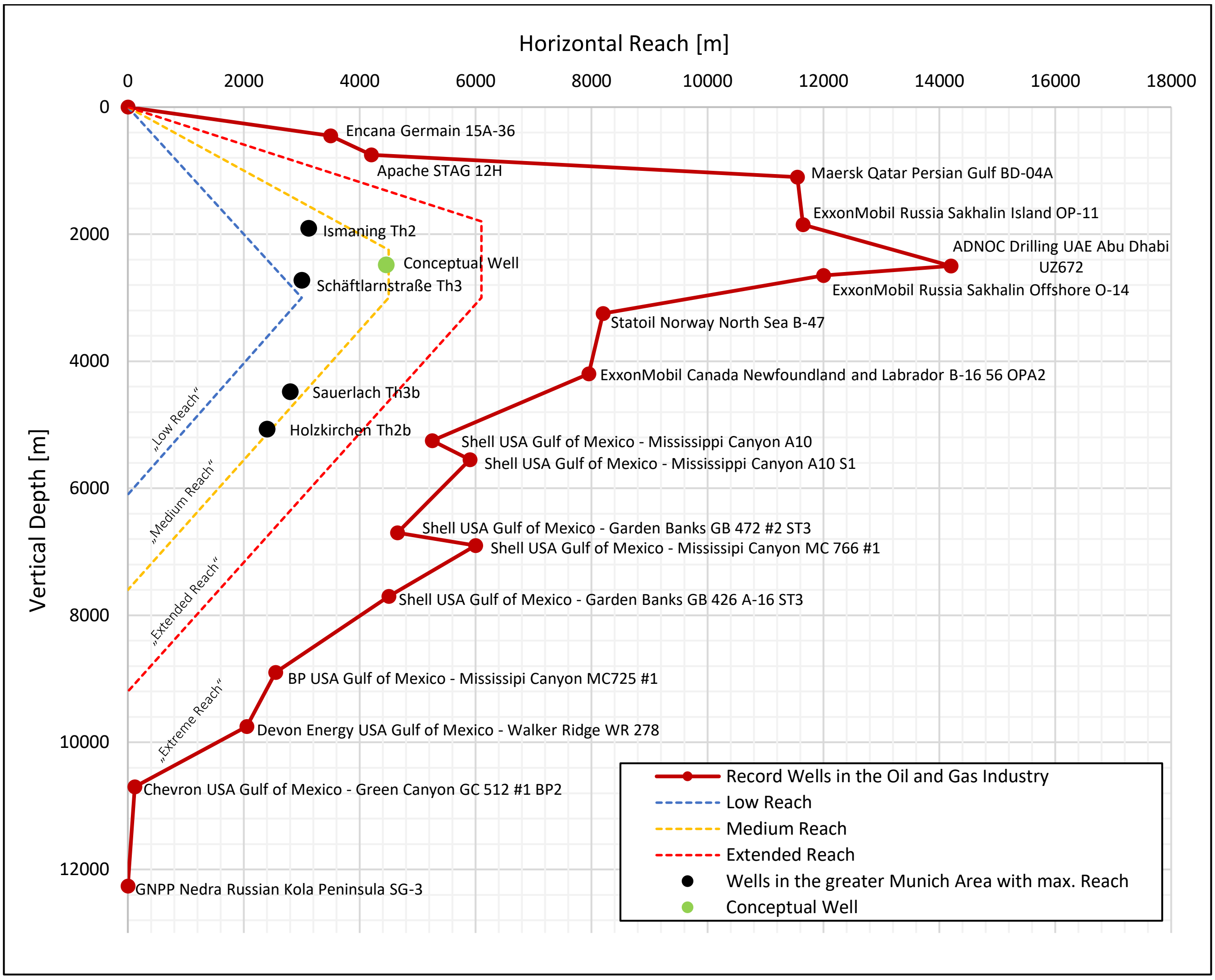

Figure 1: Wells in the greater Munich area with maximum reach compared to industry limits (Figure adapted, data according to K+M Technology Group, 2024)

## 3. State of the Art

A well-known site for ERD wells is Sakhalin Island in Russia. Many ERD wells have been drilled in this area and more than one world record has been set (Szymczak, 2021). In 2022, ADNOC Drilling set a new world record for the longest ERD well, drilled near the Abu Dhabi Islands in the United Arab Emirates. This well achieved a measured depth of 15,240 m and a horizontal reach of 14,198 m (Reed, 2022; K+M Technology Group). In Germany, the well Dieksand 6 accomplished a horizontal distance of 8,435 m (Husband et al., 2007). Other notable examples include wells drilled in the Wytch Farm field in the United Kingdom or offshore California, such as the El Capitan SA-16 (Armstrong et al., 2011).

During the planning, drilling, and completion of ERD wells, a variety of challenges must be addressed. While some of these challenges are similar to those encountered in conventional wells but significantly magnified, others are unique to the specific ERD well type (Mims & Krepp, 2003):

- Effective hole cleaning is crucial in ERD wells due to high deviation angles causing cuttings to settle on the low side of the wellbore. Factors such as pipe rotation, flow rate, fluid rheology, and solids concentration significantly influence cleaning efficiency. (Hussain, 2017)
- Torque and drag in ERD wells are significant challenges caused by the extended wellbore length and high deviation angles, leading to increased rotational torque and frictional resistance when moving the drill string. Mitigation strategies include minimizing doglegs, optimizing drilling fluids for better lubrication, and ensuring effective hole cleaning. Advanced modelling techniques, such as soft-string and stiff-string models, help to predict and manage these issues, ensuring smoother operations while at the same time achieving the required well trajectory and depth. Selecting the right drill pipes is crucial in ERD wells to handle higher torque demands and to enhance mechanical performance. Using tapered drill strings, combining heavier pipes for vertical sections and lighter ones for high-angle sections, helps to maintain proper tension and to prevent buckling, while ensuring efficient and safe drilling operations. (Mims & Krepp, 2003; Merlin ERD, 2024)
- Casing wear in wells is a significant concern due to continuous mechanical interaction between the rotating drill string and the casing wall, which can compromise well integrity. In ERD wells, wear is especially intensified by the high angles and extended nature of the wellbore. Although casing wear cannot be eliminated, it can be significantly reduced by using non-rotating drill pipe protectors, optimizing well trajectories to minimize sharp bends, and selecting wear-resistant casing materials. (Merlin ERD, 2024; Minihold, 2024)
- Running casing in ERD wells often requires specialized techniques, such as casing floating, due to excessive drag in highly deviated sections. Methods like the air-filled, mud over air, and air cavity techniques are employed to reduce the casing weight and effectively overcome drag forces. Proper planning and simulations are essential to select the appropriate method, manage dynamic loads, and avoid issues like casing collapse, ensuring successful installation to the target depth. (Minihold, 2024; Fasching, 2020)
- Managing equivalent circulating density (ECD) in ERD wells is crucial to prevent wellbore instability, as fluctuations can lead to formation fractures or influx. Maintaining a balance between a high number of rotations per minute (RPM), flow rates for effective hole cleaning and controlling ECD ensures well stability and operational safety. (Mims & Krepp, 2003)
- Well control in ERD wells presents unique challenges due to the increased probability of kicks and the difficulties in their detection, which are caused by the extended reach and complex well geometry. Advanced monitoring techniques and real-time data analysis are essential for early detection and effective management of kicks to maintain well integrity and operational safety. (Mims & Krepp, 2003)

Integrating these above-described practices allow the safe and efficient drilling operation of ERD wells.

## 4. ERD Well Concept – Challenges for SWM

In the following section, a well concept with the conventional SWM design is applied to a potential well trajectory that reaches the transition zone between medium and extended reach (Figure 1). This scenario is analysed and reviewed to identify critical aspects arising from the increased horizontal departure, which exceeds previously drilled SWM well trajectories.

### 4.1 Example Well Design

The development of the well trajectory and the determination of exact casing or liner setting depths are influenced by various boundary conditions that must be considered during the design phase.

First, the technical parameters specify a minimum surface casing diameter of 16", as a result of space requirements for the installation of the electric submersible pump (ESP). Furthermore, these parameters encompass the rate dependent dynamic water level, the resulting pump installation depth, and consequently, the first kick-off point (KOP) in the well. Additionally, predefined minimum liner overlaps of 100 m are required, along with a sufficient spacing of 150 m between end of build (EOB) and the liner setting depth to ensure the placement of the subsequent section liner hanger below the build section.

Geological parameters necessitate avoiding the first section setting depth within potentially permeable horizons and the second section setting depth within the Bausteinschichten formation. The setting depth of the third section is at the top of the Malm reservoir. The temperature gradient, pore pressure and fracture gradient must also be taken into account.

Figure 2 shows the well path of the conceptual wellbore as referenced in Figure 1 (green point) that implements the above mentioned requirements for a potential multi-well project in a relatively shallow reservoir depth. The planned casing setting depths and diameters are presented. In this design, the reservoir section can be drilled down to final depth with an 8 1/2" bit diameter, resulting in a four-section design, which is in accordance with the SWM standard design. With a TVD of approx. 2,500 m and a reach of approx. 4,460 m, the wellbore enters almost the extended reach zone as depicted in the Dog Nose plot (Figure 1).

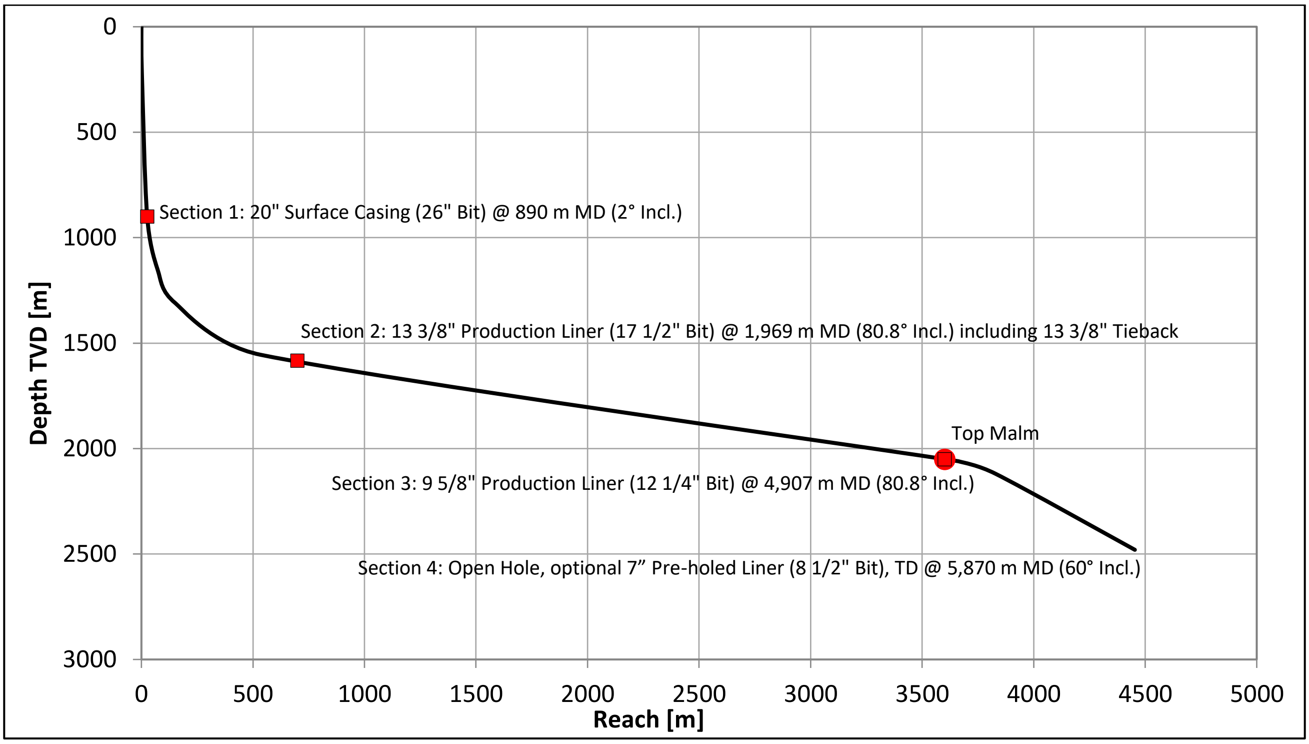

Figure 2: Well path concept - The red circle represents Top Malm, the red squares demonstrate the casing setting depths of the well design.

## 4.2 Analysis

The well path, developed in accordance with the discussed boundary conditions, is analysed applying conventional established SWM methods (drilling and liner running) that have been proven effectively in previous projects. The objective is to identify potential limitations as well as challenges and to present the findings in a comprehensive risk analysis.

Table 1 provides a summary of the investigated drilling related risks and specific characteristics for each section of the conceptual wellbore. The colour scheme used is intended to illustrate the difficulties and risks encountered during drilling operations as well as liner running (green = low risk, yellow = medium risk, red = high risk). The colour coding is based on empirical data and experiences from previous SWM projects.

Table 1: Risk assessment

| **Section** | **Torque & Drag** | **Casing Wear** | **Hydraulics** | | **Running Casing/ Liner** | **Cementing** | **Well Control** |
|---|---|---|---|---|---|---|---|
| | | | **Hole Cleaning** | **ECD Mgmt.** | | | |
| **1** | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |
| **2** | 🟩 | 🟩 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 |
| **3** | 🟨 | 🟨 | 🟨 | 🟩 | 🟥 | 🟨 | 🟩 |
| **4** | 🟨 | 🟨 | 🟨 | 🟩 | 🟨 | N/A* | 🟩 |

* pre-holed Liner (optional)

Table 1 indicates that for the first section no notable alterations in comparison to a conventional well, indicating no substantial risks, are to be anticipated.

<u>Torque and Drag:</u> Calculations indicate that high torque and drag values are expected when drilling the third and fourth sections. However, these values remain within acceptable ranges (approx. 50 kNm torque and less than 300 tons hook load) and no standard rig limits as well as drill pipe specifications are exceeded. Partial rotation of the whole drill string during run-in-hole operations can be necessary under certain circumstances to break the friction.

<u>Casing Wear:</u> Due to the extended drilling operations, the impact of side forces is expected to be more intense along the build-up interval (see Chapter 3). As a result, casing wear around the shallow kick-off point is a concern, especially during drilling and back-reaming operations in the third and fourth sections.

<u>Hole Cleaning and ECD Management:</u> Hole cleaning is a concern, particularly in the second section with the large 17 1/2" diameter bit. An unstable cutting bed in the avalanche zone followed by a stable cutting bed in the tangent section makes adequate hole cleaning a challenge. It is therefore crucial to ensure adherence to the factors mentioned in Chapter 3 that influence effective hole cleaning, particularly pipe rotation and annular velocities. However, ensuring these values presents certain challenges. The majority of SWM drilling projects are located in urban areas. Drilling in urban environment presents additional challenges as it is difficult to achieve the required drill string RPM for adequate hole cleaning performance due to noise restrictions. Furthermore, it is difficult to achieve sufficient annular velocities for good hole cleaning with the drilling rig pumps available. Previous

projects have shown that substantial reaming was required even at approx. 65° inclination in the tangent section. Consequently, it is expected that the well cleaning problems will be intensified when the inclination is increased to approx. 82°, as is the case in the example well.

According to simulations no severe hydraulic problems with the required flow rates are expected in sections 3 and 4. Nevertheless, the same parameters as mentioned for section 2 will need to be applied appropriately to ensure adequate hole cleaning performance in these sections. Furthermore, within section 4, total circulation losses are expected in the Malm reservoir. However, this is not considered as problematic (high risk) in terms of hole cleaning efficiency. The Malm has been successfully drilled multiple times in other projects with same section length as well as bit diameter and therefore, sufficient empirical data is available for this section. For these reasons, and due to the increased length, particularly in the third section, sections 3 and 4 are classified as medium risk regarding hole cleaning.

The ECD is never exceeding the fracture gradient of the formation. Thus, no ECD management issues are expected in all sections.

Running Casing/Liner: The major point with extending the reach is that the 9 5/8" liner cannot be run under its own weight. In a conventional liner installation, high compressive forces (according to simulation) would cause helical buckling followed by helical lockup. This situation is clearly illustrated in Figure 3 and Figure 4. Figure 3 shows the load distribution when reaching the final depth (Effective Tension plot). In Figure 4, the hook load plot represents the surface hook load trend throughout the entire liner operation. During the liner installation (Tripping In, green lines), helical lockup occurs for all different friction factor scenarios. This is evident from the green lines intersecting the buckling lines (yellow, brown) in Figure 3. In the hook load plot (Figure 4), this can be seen by the green lines dropping below the zero-weight-line, indicating that no forces from the surface can be transmitted to the bottom end of the string (in this case, the casing shoe). The blue lines, representing the loads during pulling the liner out of hole (Tripping Out), exceed the limits (yield strength of the drill string and hook load capacity of the drilling rig) for the more conservative friction factor combinations (Figure 3 and Figure 4). Floating therefore may be necessary, although additional rotation might still be required to run the string into the hole. Other options might include optimizing landing string weight or changing the well design to a long-string section.

Also, the 7" pre-holed liner will not run under its own weight. As the 7" liner is pre-holed, floating is not a feasible option, and the liner must be installed by rotation only. However, running a liner in the reservoir is conceptual and the setting depth must not be at total depth. A higher setting depth in the section is also possible.

Cementing: Cementation is unlikely to cause any problems in terms of fracturing the formation due to high ECDs. Simulations indicate that the ECD never exceeds the fracture gradient. A disadvantage during the cementing job in third section is that it is not possible to rotate and reciprocate the string. Consequently, due to the increased section length, this section is classified as medium risk (yellow).

Well Control: Based on data from offset wells in the nearby area, well control situations are not anticipated. However, due to the particularities of extended reach drilling discussed in Chapter 3, a high level of situational awareness and real-time data analysis should be applied to ensure the early detection of a kick. If a kick does occur, due to the geology (low maximum anticipated pore pressures), a low kick intensity is expected.

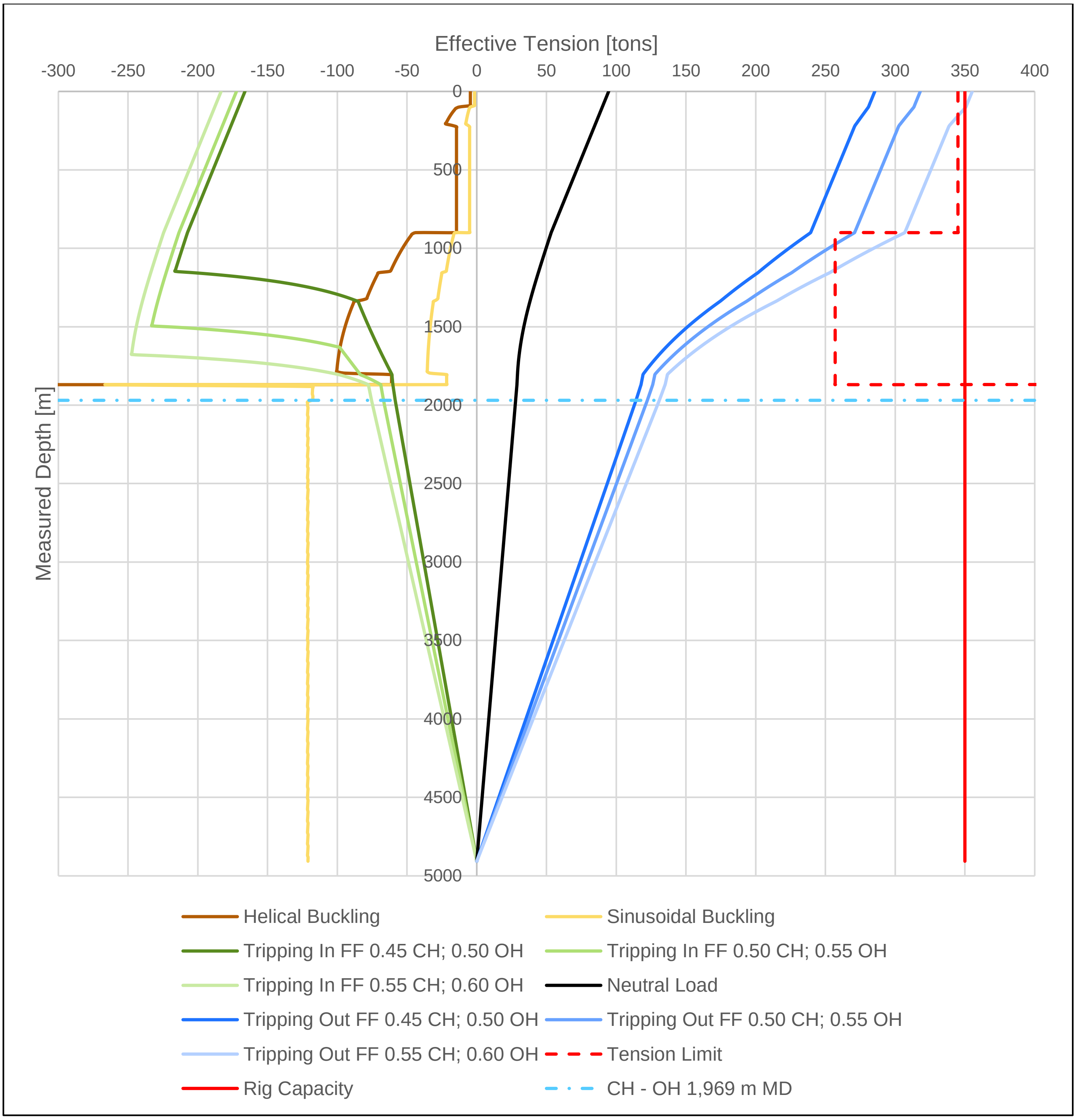

Figure 3: Effective Tension, 9 5/8" Liner, running conventional (Minihold, 2024)

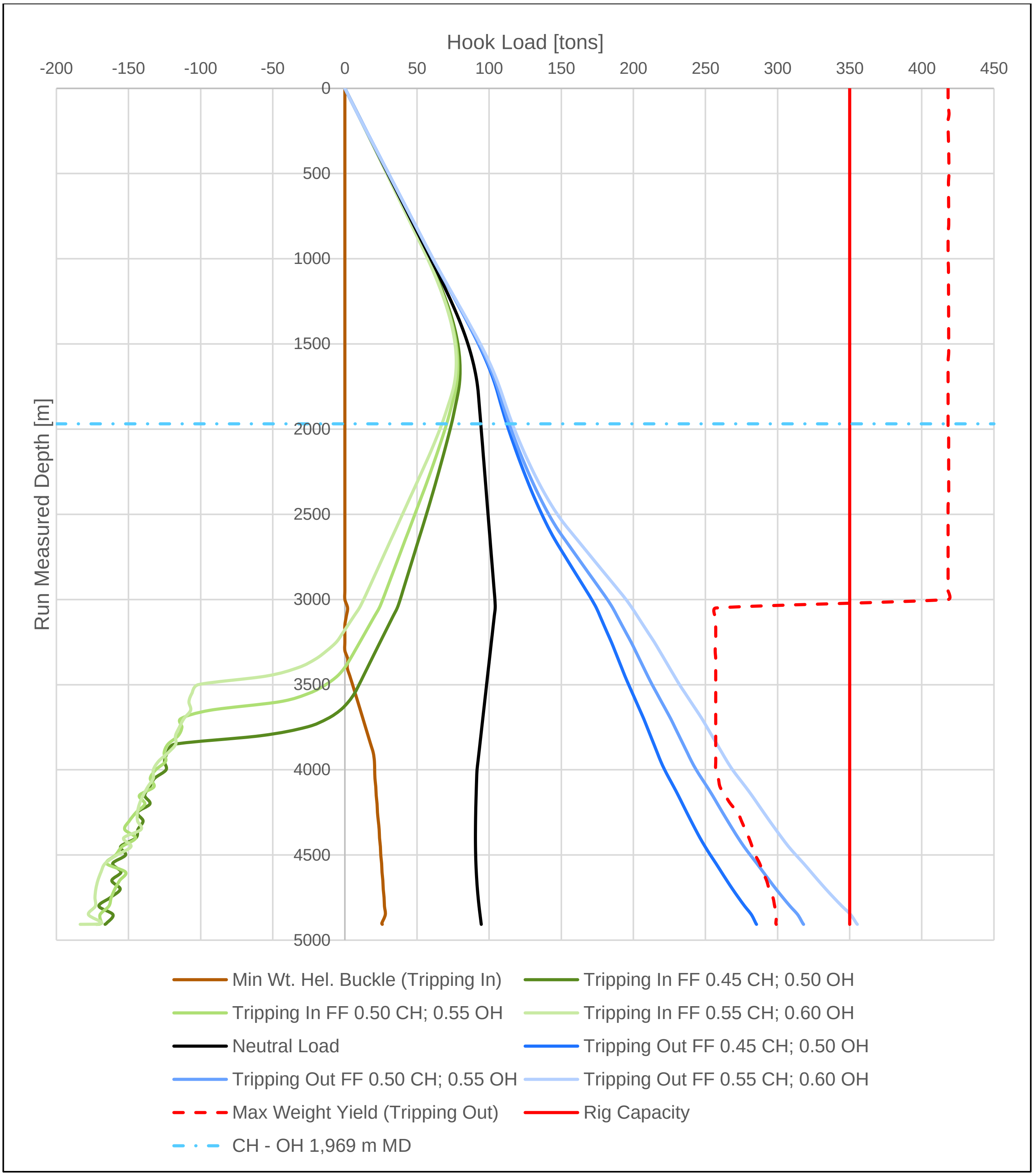

Figure 4: Hook Load, 9 5/8" Liner, running conventional (Minihold, 2024)

## 5. Conclusion and Outlook

Extended reach drilling is essential for the development of the geothermal reservoir in Munich. With future wells requiring greater horizontal departures, drilling will become increasingly challenging. Conventional methods will no longer be sufficient for these demanding conditions. As the extent of horizontal drilling increases, operations become more complex. The most critical challenges identified are hole cleaning efficiency, managing drilling torque and drag, as well as running the liners in the highly deviated sections.

This study clearly indicates that traditional approaches are inadequate for drilling extended reach wells. Especially, hole cleaning during drilling the second section and running the liner in the third section are identified as the most critical factors. Hole cleaning in the second section is challenging due to an unstable cutting bed, the large 17 1/2" bit diameter but also environmental constraints in urban areas. Additionally, for the 9 5/8" liner, high compressive forces will cause helical buckling and lockup, preventing it from being run under its own weight to section depth. To address this, the research project GIGA-M will provide solutions to drill these wells safely and efficiently. Although these solutions can be derived from the oil and gas industry, modifications will be necessary (e.g. liner floating) to meet the specific requirements of geothermal wells. Upcoming publications will present these customized solutions for geothermal drilling.

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