



SPE 39007

Drilling Optimization Software Verified in the North Sea

R. K. Bratli*, G. Hareland**, F. Stene*, G. W. Dunsæd* and G. Gjelstad***

* Saga Petroleum ASA

** New Mexico Institute of Mining and Technology

***HACO Inc

Copyright 1997, Society of Petroleum Engineers, Inc.

This paper was prepared for presentation at the 1997 SPE LACPEC Conference in Rio De Janeiro, Brazil, August 30 - Sept. 2, 1997.

This paper was selected for presentation by an SPE Program Committee following review of information contained in an abstract submitted by the author(s). Contents of the paper, as presented, have not been reviewed by the Society of Petroleum Engineers and are subject to correction by the author(s). The material, as presented, does not necessarily reflect any position of the Society of Petroleum Engineers, its officers, or members. Papers presented at SPE meetings are subject to publication review by Editorial Committees of the Society of Petroleum Engineers. Electronic reproduction, distribution, or storage of any part of this paper for commercial purposes without the written consent of the Society of Petroleum Engineers is prohibited. Permission to reproduce in print is restricted to an abstract of not more than 300 words; illustrations may not be copied. The abstract must contain conspicuous acknowledgment of where and by whom the paper was presented. Write Librarian, SPE, PO Box 833836, Richardson, TX 75083-3836, U.S.A., fax 01-972-952-9435.

Abstract

This paper presents the introduction, application and verification of a new drilling optimization approach. During the past decades rate of penetration (ROP) models for all types of drilling bits were developed and verified. The unique software uses these models in a new approach that optimizes the drilling cost on each hole section. The simulation of ROP every foot gives the capability to simulate the effects of all operating conditions, bit design, bit wear and formation properties.

All the penetration rate models used can be inverted to solve for rock strength if ROP, operating conditions, lithology percentage and field reported bit wear is known. This imply that if one well has been drilled, and the penetration rates are inverted, a foot by foot strength is obtained, by integrating over each individual bit run until the field reported bit wear matches the calculated. This strength is then used as input for simulation, and it is shown that the drilling cost for one particular 12,25" section can be reduced as much as 45-50 percent by changing bit design and operating conditions.

This approach has been verified with North Sea data where the generated rock strength from the 12,25" section has been used as input to simulate the ROP and rotating time. These simulations compare well

with the measurements of ROP, made in the two following wellbores drilled in the same field. Simulating ROP using drilling data from a well in a nearby field also gave promising comparisons.

Introduction

The DRilling OPtimization Simulator (DROPS) is developed to reduce the cost of future wells based on a Geological DRilling Log¹ (GDL), created from the data collected in a previous well drilled in the same area. The GDL is created using ROP models²⁻³ inverted to calculate rock compressive strength. The simulator has the capability of simulating any combination of operating conditions, bit designs, pull depths, hydraulics, WOB and RPM⁴. The basic idea behind DROPS is to simulate the drilling operation prior to the actual drilling, and to find the optimum cost level. Simulations to verify the software (drill behinds) have been performed using actual field data from the North Sea, provided by Saga Petroleum ASA, well A and B. Data from well C, provided by Statoil, have also been used in the drill behind simulations. The simulated ROP results from the drill behind compares well with the results for actual measured ROP and cumulative rotating time, which are promising for further development and application of the method. Based on the comparison some cost optimizations for future wells in this region have also been performed. The cost reductions obtained indicate potential cost savings of 45-50 percent of total drilling cost per well, compared to the current industry practice in the area. By using this methodology in the planning process the most cost effective drilling program can be obtained. Further testing and implementation of

DROPS in Saga's operations will take place during this year, and will be reported upon at a later stage.

Drill Behind - Procedure for DROPS Verification

When comparing actual and simulated data the input files for the program (DROPS) contains bit records, the standard mudlogging data (cuttings lithology, drilling parameters) on a meter by meter basis. The actual field collected data from well A was used to generate the meter by meter rock compressive strength log (GDL). From well B the average ROP, WOB and RPM for every 20 to 50 meter were calculated. This was done to reduce the amount of manual input, without corrupting the field data. The simulations for well C uses data recorded every meter. The ROP for well B and C were simulated using the strength profile from well A and the operating conditions from well B and C. This was then compared with the actual ROP data obtained in the field.

Post Analysis

The 12.25" hole section on two wells operated by Saga Petroleum ASA, well A and well B, have been analyzed. The Statoil, operated well C, from the same area, was also studied. A map of the area is shown in Figure 1 indicating that the wells are found in different structural elements. They seem, however, to penetrate the same lithostratigraphic succession, but some of the lithologic units are thinning out in well C.

Using the inverted ROP models from DROPS a strength log or GDL was generated for well A. This GDL was then utilized in well B to make a prognosis of the drilling rate (ROP), based on the planned operational parameters. As drilling progressed, the prognosis was updated with the actual data for the section, and a comparison was made with the measured ROP for the section drilled.

Bit Run # 1

In Figure 2 is shown a comparison between the actual and computed ROP for PDC Bit #1, one of the 4 bits used to drill this section in well B. As can be seen from this illustration the measured and calculated ROP show similar trends, especially at the end of the bit run where they both pick up the top of a hard stringer. Here the ROP drops dramatically for both the measured and the calculated ROP. Figure 3

illustrates the actual and calculated cumulative rotating hours for the bit, and they are in good agreement.

In Figure 4 the bit wear predictions from DROPS are plotted versus depth. Because of the high RPMs run on the bit the gage wears faster than the center of the bit. The wear reported for this bit was a 6 wear on the gage and a 2 in the bit center. The model predictions match the field reported wear very well. The more rapid wear in the hard stringer is due to the combination of increased WOB, rock strength and abrasiveness.

Bit Run # 2

The second PDC bit also used on the B well has a higher cutter density than Bit #1 and does therefore have a better wear characteristic. This bit was also simulated in the DROPS, which has the capability of simulating any PDC bit design and nozzle combination, and compared to the field reported ROPs every 20 meter. The results are plotted in Figure 5.

The results in Figure 5 indicate again that DROPS is matching the ROPs very well. The rotating time versus depth plot is shown in Figure 6. As can be seen from this Figure it is only in the beginning of the bit run the calculated and actual rotating time differ, in the rest of the bit run they are parallel which indicate that they are identical, which mean that the DROPS predictions are reasonable.

Bit Run # 3

The third bit on the section was a 437 IADC insert bit run on motor. The major objective with this bit was to control wellbore angle, and no efforts were made to optimize the operating conditions. Using the GDL from the A well and the operating conditions from the B well on the tricone bit, the DROPS ROP predictions can be compared to the actual ROP's on the correction run. The comparison is shown in Figure 7. The ROP trends for the tricone bit match, even if the offset might be high in parts of this run.

Bit Run # 4

The C well was drilled with one bit most of the 12,25" section, but the bit was allowed to walk and build deviation angle. DROPS had seen similar predictions from earlier simulations. Applying the

GDL created from the well A, using operating data from well C, the ROPs match, which indicate that DROPS has the same predictions, as can be seen in Figure 8. Because the C well had a shorter hard stringer ending at 3520 meter the ROP estimation using the GDL from the A well is under-predicting the ROP from about 2520 to 2610 meter because the hard stringer was 90 meter thicker in well A.

The Rock Strength Profile (GDL) Evaluation

After drilling of well B the GDL was generated. A comparison of the A and B well GDL is shown in Figure 9, and they show a remarkable resemblance. The same comparison between well A and C was done and is shown in Figure 10, again with good agreement.

Cores have been taken in both wells A and B, as well as other wells in the area, and triaxial tests have been run. These cores are taken in the reservoir section in the 8.5" hole. Based on the triaxial data, failure strength at 2.0 MPa confinement have been plotted versus the GDL from the 12.25" and 8.5" hole sections of Well A. The confinement (2.0) is approximately the overbalance pressure used during drilling. These strength values are plotted in Figure 11, and shows that the calculated GDL give strength levels comparable with the measured data from cores. A direct comparison cannot, however, be done, since the measured and calculated data are not from the exact same lithological units.

DROPS Economical Outputs

The standard model for cost has been used when optimizing drilling cost. The optimum drilling cost is obtained when the total cost of drilling a section becomes a minimum, which is not necessarily when the instantaneous drilling rate becomes largest. To achieve this optimum many scenarios of bits and operating parameters have been simulated.

Learning Curve

The method used for the learning curve shown in Figure 12, was to start with the default bits and parameters used on well A. Then different bits were tested and the parameters for the bits optimized. Optimum operating conditions for each bit combination were found after a few simulations. To further decrease the costs, other bit combinations were tested (See Figure 12 where cost peaks then a

decrease is seen in the learning curve). The operating parameters, section lengths and pull depths were changed for each new bit combinations. Each combination was then optimized. It is also very important to use reasonable limits on operating parameters. The bits in the recommended simulations had an average wear of no more than 6.5.

The economic analysis of the 12.25" sections uses a rig rate of 185,000 USD. The actual bit cost, trip time of 1 hour per 1000 feet round trip, a connection time of 5 minutes per 30 foot and the actual rotating time. The learning curve for the 12.25" section in Figure 12 shows a clear reduction in actual drilling cost. The optimum bit and drilling parameters for the lowest cost drilling was obtained by performing the simulations in less than two avoiding experimentation in the field. The optimum drilling recommendation simulates savings of more than 1.2 million USD on the 12.25" section alone. Including the same type of analysis on the 8.5" section gives a possible drilling cost reduction of more than 3 million USD on one well. The concept of applying the learning curve approach on the simulator before the fact, will in this case save the operator large amounts of money.

Conclusions

1. The drilling optimization simulator (DROPS) has been verified with actual drilling data from three North Sea wells.
2. The DROPS ROP predictions for both PDC and tricone bits using a nearby GDL have shown to compare well with the field reported ROPs.
3. DROPS indicate that drilling cost savings can be as much as 40 to 50 percent of total drilling cost, using the optimum simulations.
4. The GDL rock strength logs from the wells match well which is a clear indicator that the total DROPS simulation concept works.
5. It is recommended to continue to use DROPS in post analysis and planning on new well.

Acknowledgments

We like to thank Saga Petroleum ASA for permission to publish the data herein as well as Ingolf Jolma of Statoil for data from the C well.

References

- 1 Onyia E. C., "Geological Drilling Log (GDL): A Computer Database System for Drilling Simulation" paper SPE 13113, presented at the 1984 SPE Annual Technical Conference and Exhibition, Houston, TX Sept. 16-19, 1984.
- 2 Hareland, G. and Hoberock, L. L.: "Use of Drilling Parameters to Predict In-Situ Stress Bounds" paper SPE 25727, presented at the 1993 SPE/IADC Drilling Conference, Amsterdam, Feb. 23-25, 1993.
- 3 Hareland, G., and Rampersad, P.R.: "Drag Bit Model Including Wear", paper SPE 26957, presented at the III LACPEC meeting, Buenos Aires, April 27-29, 1994.
- 4 Rampersad P.R., Hareland G. and Boonyapaluk P.: "Drilling Optimization of an Oil or Gas Field" paper SPE 27034, presented at the III LACPEC meeting, Buenos Aires, April 27-29, 1994.

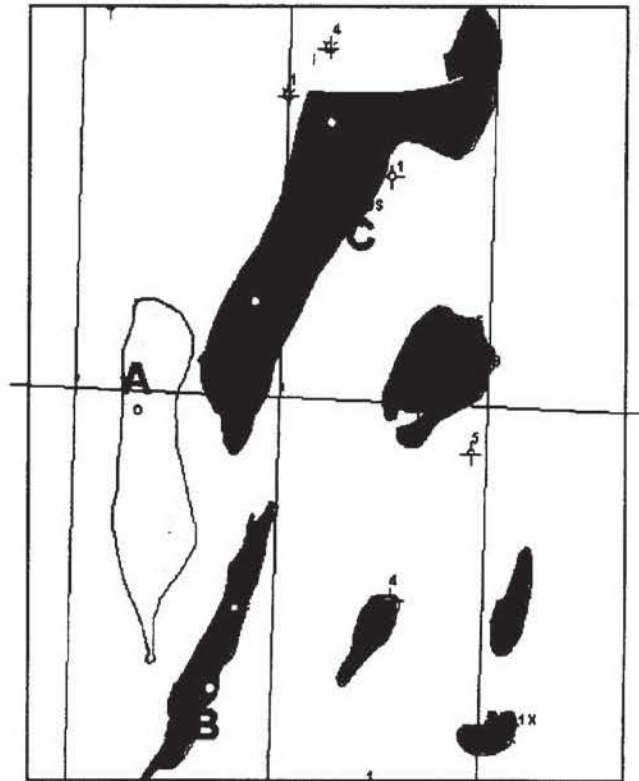


Figure 1. Map illustrating the distances between the A, B and C well. (The distance between well A and B is approximately 12 kilometers.)

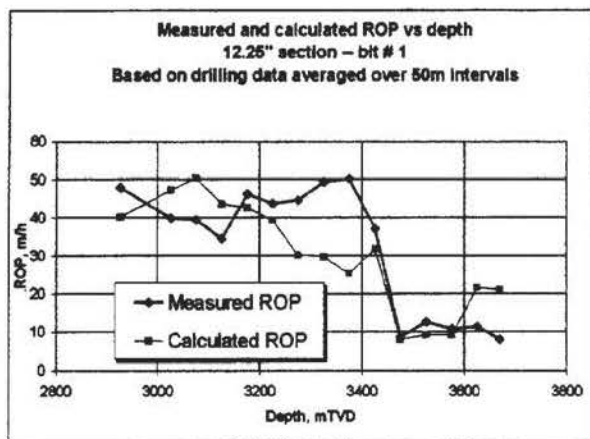


Figure 2. Comparison between the actual and computed ROP for PDC Bit # 1 used on well B.

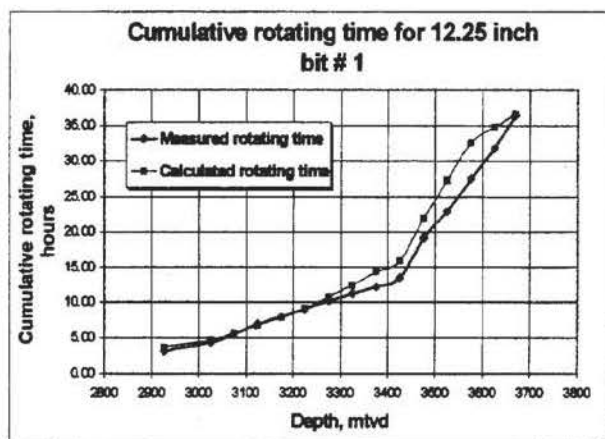


Figure 3. Illustration of the actual and calculated cumulative rotating hours for bit # 1.

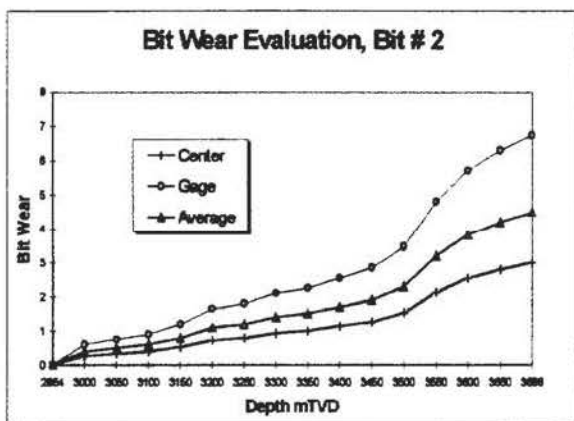


Figure 4. The bit wear prediction from DROPS is plotted versus depth.

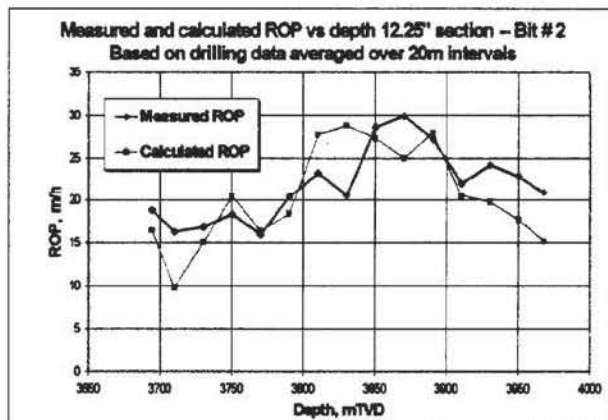


Figure 5. Comparison between the actual and computed ROP for PDC Bit # 2.

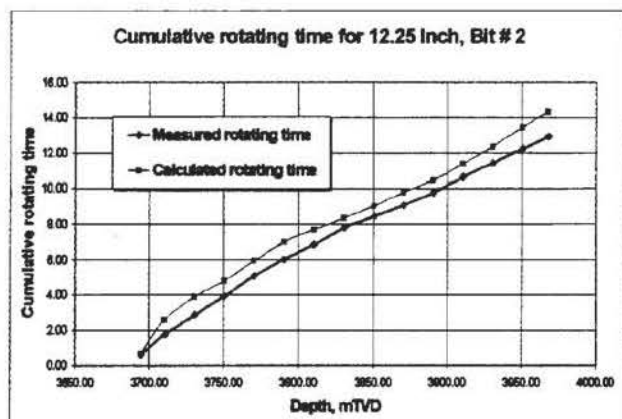


Figure 6. Illustration of the actual and calculated cumulative rotating hours for bit # 2.

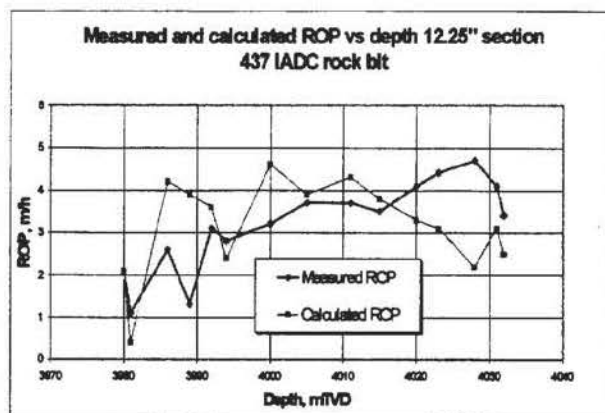


Figure 7. Comparison between the actual and computed ROP for the 437 IADC rock bit.

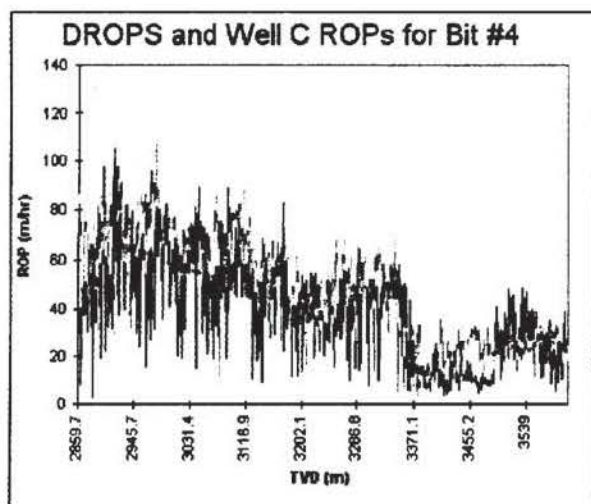


Figure 8. ROP prediction from DROPS compared with the ROPs for well C.

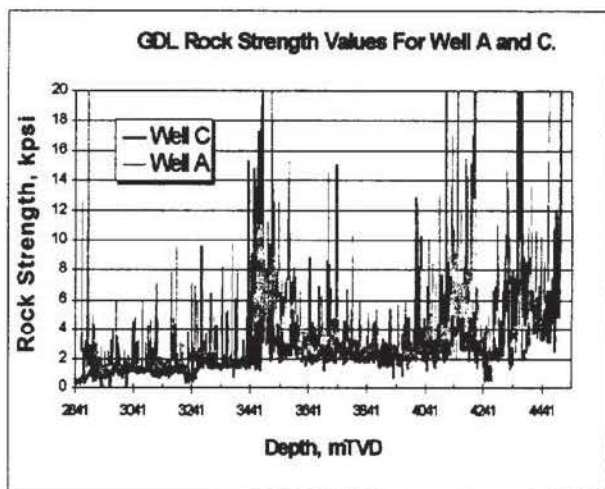


Figure 9. Rock strength Values for well A and B.

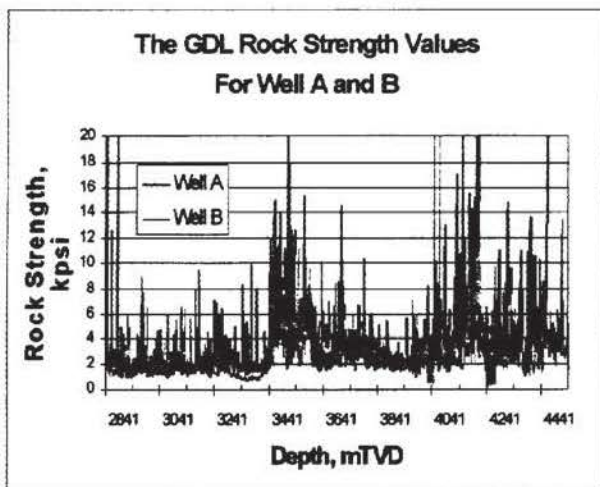


Figure 10. Rock strength values for well A and B.

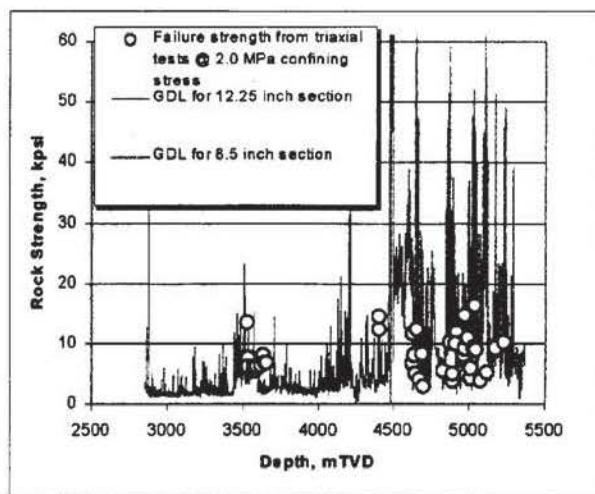


Figure 11. Based on triaxial data failure strength at 2.0 MPa confinement plotted versus GDL from the 12.25" and 8.5" hole sections.

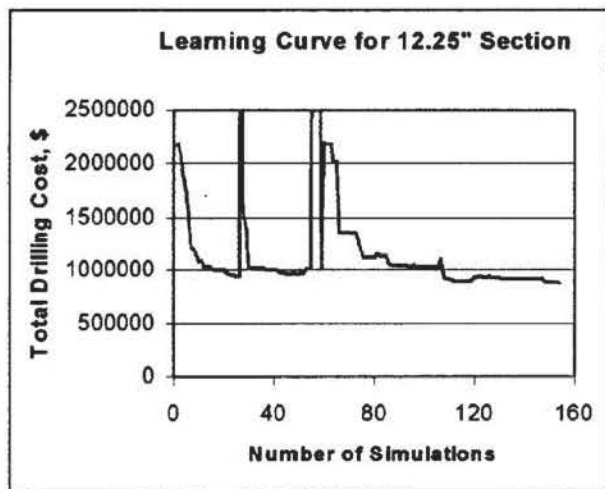


Figure 12. Learning curve for the 12.25" section, using the Drilling Optimization Simulator.