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GEOTHERMAL DRILLING COST AND DRILLING EFFECTIVENESS

Sverrir Thorhallsson[1] and Bjorn Mar Sveinbjornsson
[1]Iceland GeoSurvey (ÍSOR),
Grensásvegur 9, 108 Reykjavík,
ICELAND
sverrir.thorhallsson@isor.is, bms.isor@gmail.com

ABSTRACT

The cost of geothermal wells and field development is about 40% of the total investment cost for new high-temperature geothermal plants. This “up front” cost makes geothermal plants more expensive to build than conventional plants and because of this and the perceived risk, a lot of attention has been focused on ways to reduce this cost. This paper describes the drilling cost structure and what factors affect the cost. About half of the well cost is related to the time charges of the drilling rig (day rates) and associated equipment and thus ways of reducing the time it takes to drill the well is one way of reducing the overall cost. There is surprisingly little published data available on the breakdown of geothermal drilling costs, because of the competitive nature of the drilling market and confidentiality clauses.

1. INTRODUCTION

Drilling performance of 73 high temperature and reinjection wells drilled in the period 2001–2009 in the Hengill field in Iceland was analysed and the statistical level of risk assessed (Sveinbjornsson, 2010). The following paper reports the main topics of that reference. The number of working days to complete each depth section of the well (4 sections) was analysed and the time broken down to show how much was spent on drilling, tripping, casing, cementing, logging etc. The results were then grouped according to which design was used and technology applied. Cost calculations were made, based on market prices, as the real cost was not made available. The time breakdown had similarly to be worked out from the geological reports as the key performance indicator (KPI) data was confidential.

2. TIME ANALYSIS

The most common type of high temperature well in the Hengill field is of a “large diameter” casing program. The drilling is divided into four sections. The initial pre-drilling (Section 0) is by a small rig (50 t) with a 26" bit down to 90 m for a 22½" surface casing, followed by Section 1 drilled by a larger rig (200 t) with a 21" bit to 300 m for the 18⅝" anchor casing, Section 2, inclined or directional drilling with a 17½" bit to 800 m for 13⅜" production casing, and Section 3 with a 12¼" bit to a depth of 1,800 to 3,300 m for 9⅝" slotted production liner. To compare the drilling time for different wells the respective numbers of workdays were normalised for a reference well of that design and the average depth of the group which was 2,175 m. Table 1 shows the results.

TABLE 1: Normalised workdays for large diameter reference wells

Drilling Project			**Workdays total**			**Beta-PERT**		
Section	Drilled	Number	Lowest	Most likely	Highest	Average	Standard deviation	
	(m)	(n)	(a)	(m)	(b)	(t_e)	(s)	%
0	90	23	3	5	11	5.7	1.3	22.8
1	210	35	5	8	14	8.5	1.5	17.7
2	500	48	6	10	18	10.7	2.0	18.7
3	1,375	50	10	16	38	18.7	4.7	25.1
Total	*2,175*					*43.5*	*5.5*	*12.6*

The number of wells varies as fewer reports were available on the sections of pre-drilling and drilling for the anchor casing than the sections of drilling for the production casing and the productive open hole. Out of the 73 wells, drilling of a section in 14 wells ran into unusual difficulties which led to an excessive number of workdays and increased material cost. The difficulties were mostly due to anomalous geological conditions. As excessive cases of this nature would skew the distribution of normal drilling progress it was decided to analyse the frequency of them separately but exclude from the reference class six of these cases which deviated more than 3 standard deviations from the average. Figure 1 below shows the distribution of the resulting reference class for the total of workdays in normal drilling of large diameter wells. The distribution is of the asymmetric Beta-PERT type where the most likely value is lower than the average. With 95% confidence the workdays lie between 33.4 and 55.5 days. The average for the empirical data of the total is 43.5 days.

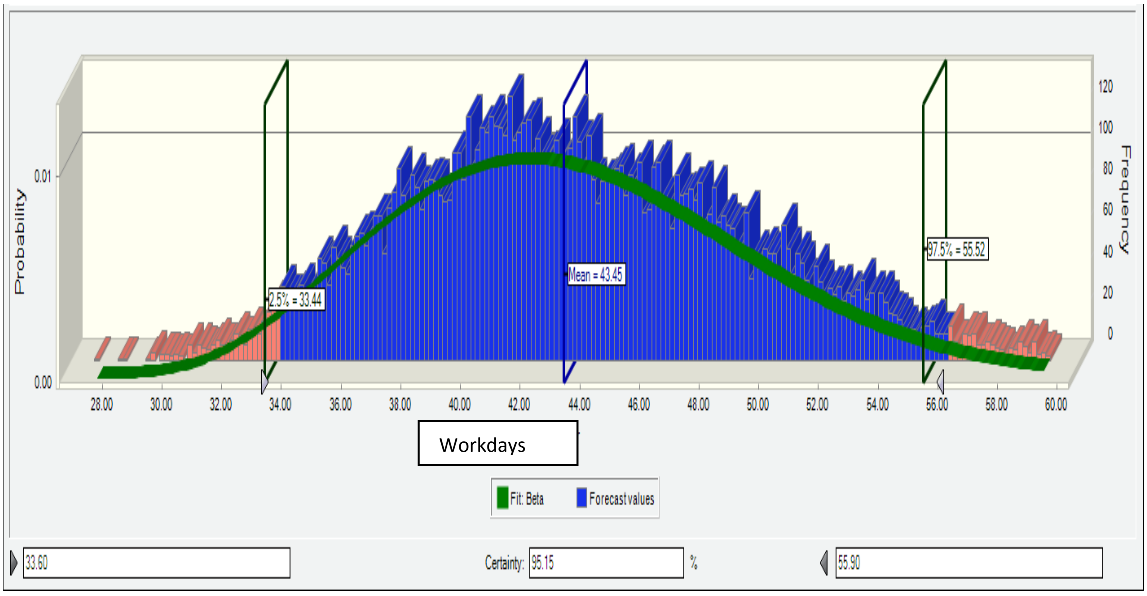

FIGURE 1: Distribution of total workdays for large diameter reference wells to 2,175 m

The workdays were also analysed for each section of drilling and the time used for different activities such as actual drilling, running and cementing casing, delays due to drilling problems, logging, installation of wellhead and other reasons for delays. The results of that analysis are shown in Table 2.

TABLE 2: Workdays of different activities for large diameter reference wells

Holes			**Workdays total**		**Workdays of different activities**					
Section	Drilled	Number	Average	St. dev.	Drilling	Casing	Problems	Logging	Completion	Other
	(m)	(n)	(t_e)	(s)	(d)	(d)	(d)	(d)	(d)	(d)
0	90	23	5.7	1.3	2.4	1.9	0.4	0	0.9	0.1
1	210	35	8.5	1.5	3.0	2.2	1.0	0.8	1.1	0.4
2	500	48	10.7	2.0	5.0	2.4	0.5	1.1	1.3	0.4
3	1,375	50	18.7	4.7	9.4	1.1	1.9	4.0	1.6	0.7
Total	*2,175*		*43.5*	*5.5*						

Besides the analysis for the reference well of the “large diameter” type it is of interest to compare the number of workdays to that of the “regular diameter” casing program of with casing diameters of 18⅝" surface, 13⅜" anchor, 9⅝" production casing and a 7" slotted liner. The results are shown in Table 3. The number of wells varies according to the availability of reports. The average and the standard deviation are calculated assuming a Beta-PERT distribution for the workdays. The total workdays for the regular diameter wells are 46.9 days but 44.1 days for the large ones. The difference is insignificant, but if any it takes slightly less time to drill the large diameter wells.

TABLE 3: Workdays for regular and large diameter wells to 2,175 m

	Section 0			**Section 1**		
	Number of holes	Work-days	St. Dev. (s)	Number of holes	Work-days	St. Dev. (s)
Regular diam.	17	6.3	2.6	21	8.7	3.8
Large diam.	23	6.1	2.2	35	8.4	2.3

	Section 2			**Section 3**			**Total**	
	Number of holes	Work-days	St. Dev. (s)	Number of holes	Work-days	St. Dev. (s)	Work-days	St. Dev. (s)
Regular diam.	20	10.6	4.2	22	21.3	7.6	46.9	9.8
Large diam.	48	10.5	2.8	50	19.1	6.6	44.1	7.8

3. COST ANALYSIS

The cost structure is such that there is a day rate for the drilling rig and crew and also for the many services engaged such as for cementing, directional drilling, drilling mud, logging etc. These daily costs vary according to the technology requirements of the equipment, geographic area, and prevailing market conditions. The unit material costs on the other hand reflect the commodity prices for steel, cement, fuel oil etc. and their overall cost is therefore more predictable as the usage quantity can be calculated. On top of this the remoteness of the site and proximity to supplies and services affect these costs.

The cost of drilling the reference well of the large diameter program was calculated on the basis of the number of workdays required for each section of the drilling. A breakdown of cost for different sections is shown in Table 4.

TABLE 4: Average cost of a large diameter reference well to 2,175 m

Component	Cost ($)	(%)
Site, cellar, water supply	400,000	8.6
Moving in the smaller drill rig	106,000	2.3
Moving in the larger drill rig	255,000	5.5
Site and Moving total	*761,000*	*16.3*
Section 0, small rig, 26” to 90 m for 22½” surface casing	332,000	7.1
Section 1, large rig, 21” to 300 m for 18⅝” anchor casing	716,000	15.3
Section 2, large rig, 17½” to 800 m for 13⅜” production casing	1,303,000	27.9
Section 3, 12¼” to 2.175 m for 9⅝” slotted production liner	1,556,000	33.4
Total	*4,668,000*	*100*

It is assumed that a small drill rig is used for Section 0 to 90 m, but the Sections 1, 2 and 3 are drilled by a larger rig. Note that this is the average cost of a large diameter reference well where unusual problems in 6 wells that led to deviations in excess of 3 standard deviations from the average have been excluded. The risk of such problems was dealt with separately (Figure 6). Table 5 shows the time cost and material cost for each section as well as the percent of the total cost.

TABLE 5: Breakdown of cost of a large diameter reference well to 2175 m

Item of Cost	Section 0 Pre-Drilling ($)	(%)	Section 1 Anchor ($)	(%)	Section 2 Pro-duction ($)	(%)	Section 3 Open hole ($)	(%)	Total ($)	(%)
Time cost total	172,665	52.0	430,193	60.1	569,560	43.7	1,093,825	70.3	2,266,243	35.2
Material cost total	159,424	48.0	285,777	39.9	733,375	56.3	462,918	29,7	1,641,494	48.4
Site etc.									400,000	8.6
Moving small rig									105,625	2.3
Moving larger rig									255,000	5.5
Total	*332,089*	*100*	*715,970*	*100*	*1,302,935*	*100*	*1,556,743*	*100*	*4,668,362*	*100*

4. REFERENCE CLASS FOR THE TOTAL COST

To obtain an estimate of the variance in total cost Monte Carlo simulations were carried out using probability distributions for the uncertainties in the number of workdays, the unit costs of material, and day rates for the drilling rigs. Figure 2 shows the distribution for the total cost of the reference well of the large diameter program. Note that here the cost of the drill site, cellar and water supply, as well as the cost of moving rigs in, are included. The average obtained for the simulation is $4,665,000, compared to the total cost of $4,668,000 obtained in Table 5. The standard deviation was found to be $359,200. The cost lies with 95% confidence within the limits $4,101,000 and $5,365,000. Sensitivity analysis shows that the number of workdays causes most of the uncertainty, 76.5% in Section 3, 13.4% in Section 2, 5.9% in Section 1 and 1.9% in Section 0. Graphs for accumulated probability indicate that in 30% cases the cost exceeds $4,825,000 and in 30% cases the cost will be lower than $4,457,000.

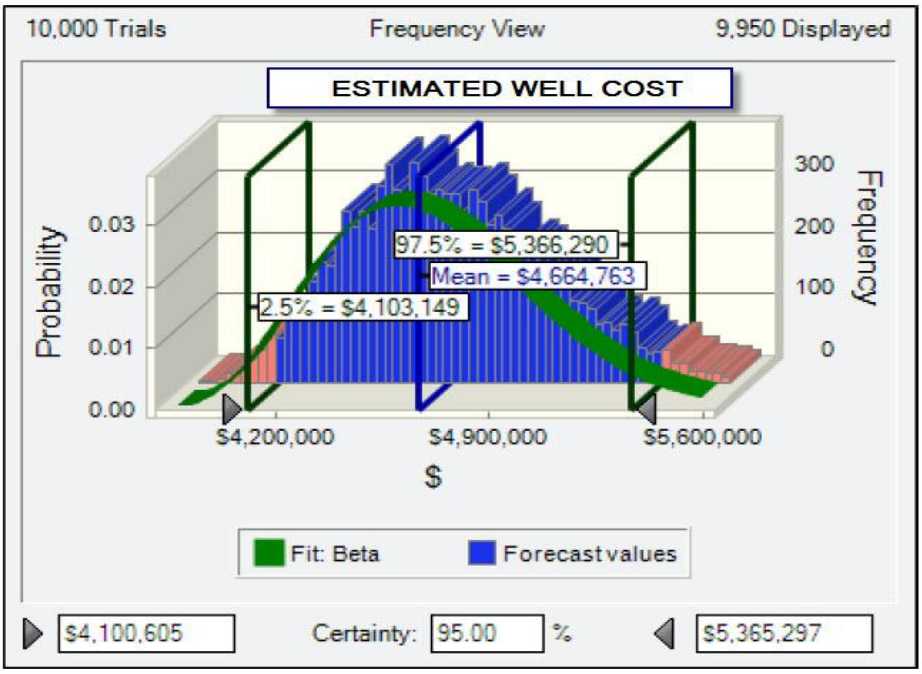

FIGURE 2: Total cost of the large diameter reference well to 2,175 m

5. WORKDAYS AND COST WITH DEPTH

Figure 3 shows the depth of a large diameter reference well as a function of the number of workdays. Note that workdays for moving drill rigs in are included here. The work components *drilling and problems* are counted as active drilling time but *moving in, setting up the rig, casing, cementing, logging, well completion and other* are counted as waiting time.

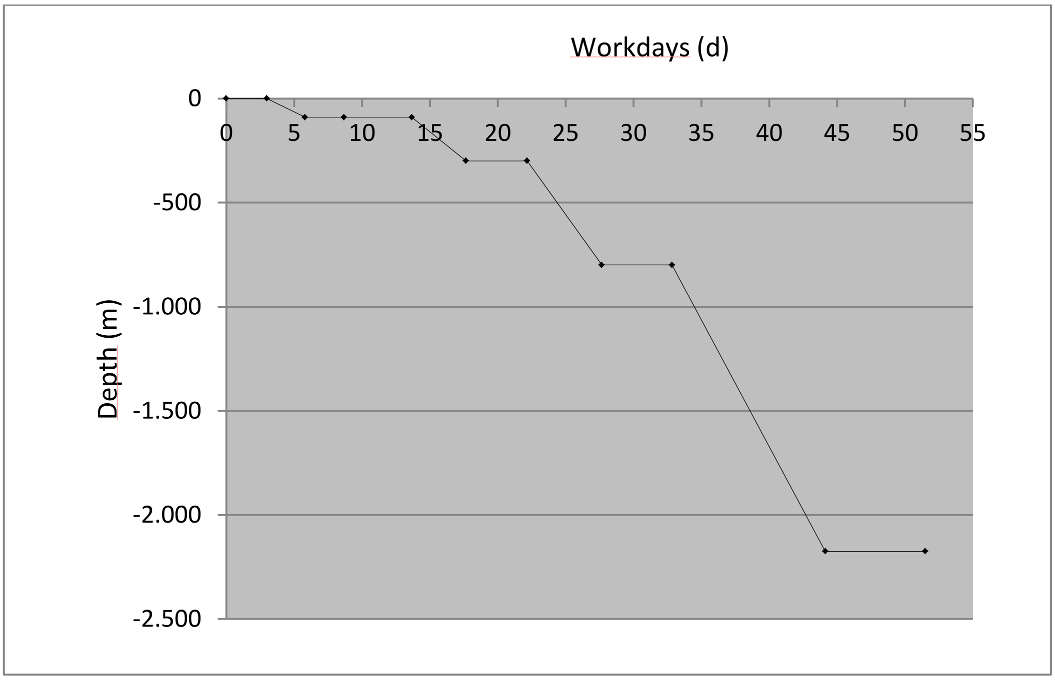

FIGURE 3: Depth of the large diameter reference well versus number of workdays

Figure 4 shows how the cost of a large diameter reference well increases with well depth. The cost of drill site, cellar, water supply, and moving rigs in, is included here. This graph is useful in estimating the cost of each section and what would be lost if section 3 must be redrilled. Also how much it would cost to deepen the well beyond the depth of a reference well.

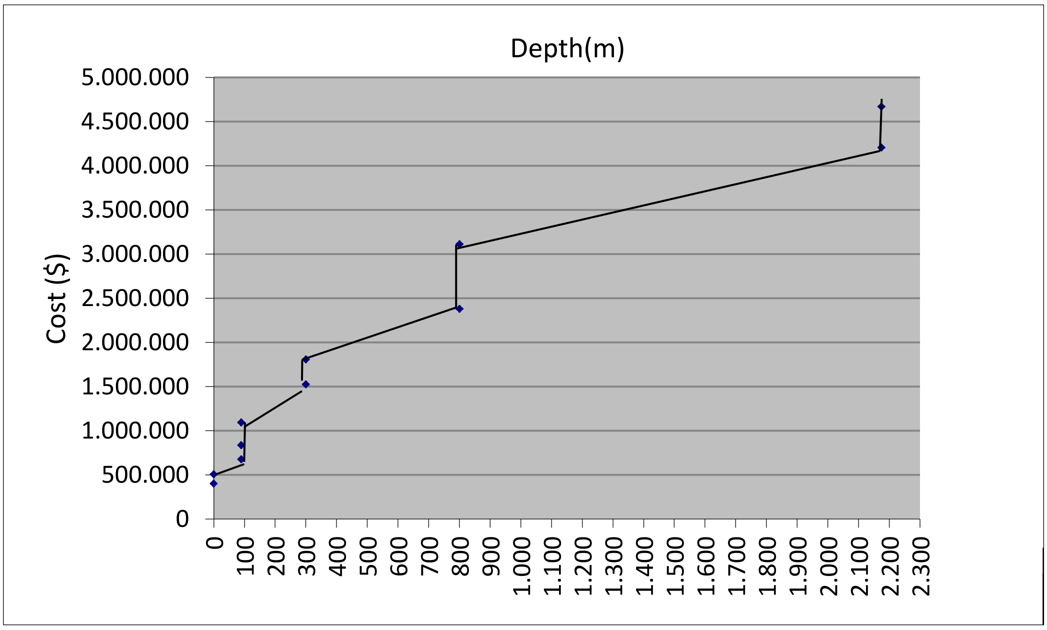

FIGURE 4: Cost of the large diameter reference well versus depth

Figure 5 shows how the cost of the well increases with the number of workdays.

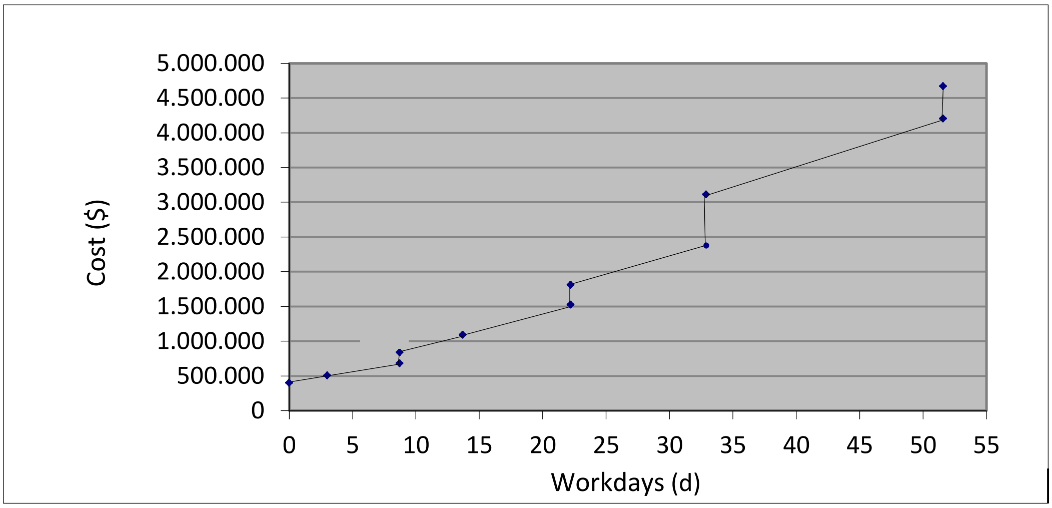

FIGURE 5: Cost of large diameter reference well versus number of workdays

6. UNUSUAL DRILLING PROBLEMS

In the Hengill field 14 of the 73 wells encountered unusual problems which led to additional cost. The main causes were difficult geological formations where the bit got stuck in the hole. In 6 cases or 8.2% the additional cost exceeded 3 standard deviations of the reference class (3 x $359,200).

Figure 6 shows the number of wells where the additional cost due to unusual problems exceeded \$250,000. This distribution can be of aid in estimating additional risk due to such unusual problems on top of the risk included in the statistical distribution of the reference well.

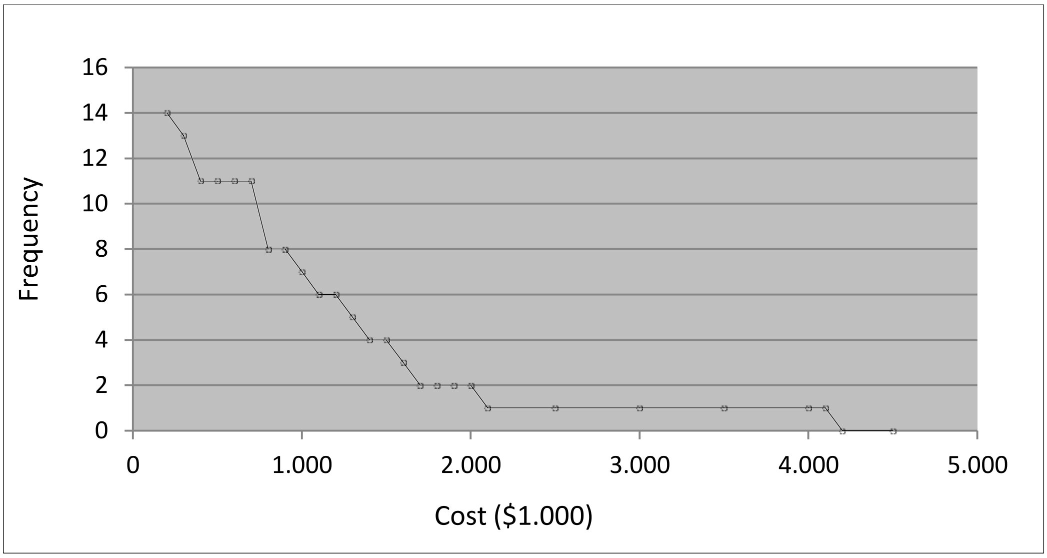

FIGURE 6: Number of wells with additional cost due to unusual problems exceeding \$250,000

7. POWER OUT OF WELLS

The overall economics of a geothermal power project is strongly influenced by the power output per well, or how much can be reinjected, which is also considered in evaluating the drilling effectiveness. Table 6 shows the power output per drilled geothermal well and per productive well in the Hellisheiði region of the Hengill field. It is of interest to note that the difference between the regular and large diameter wells appears insignificant.

TABLE 6: Power output of wells

Diameter	**Drilled wells**	**Productive wells**	**Power per drilled well (MW_e)**	**Power per productive well (MW_e)**
Large diameter	38	33	5.8	6.7
Regular diameter	15	13	5.7	6.6
Total	*53*	*46*	*5.8*	*6.7*

The data bank could be used for other comparisons such as vertical vs. directions wells, drilling with water only or managed pressure drilling by aerating the water. Only 4 of the wells in the Hengill field were however drilled vertical. A comparison with vertical wells is therefore not reliable. For success metrics, comparisons were made between the Injectivity Index (II) at the end of drilling and the confirmed flow-output (MW_e or kg/s of steam and water) of the well. The results indicate that to obtain reliable predictions of yield on the basis of the Injectivity Index one must also consider reservoir conditions and enthalpy of the expected discharge. Such predictions would be valuable for decisions, whether to deepen a well or redrill the last section as a sidetrack or “fork”.

8. COMPARISON BETWEEN ICELAND AND KENYA

Thomas Miyora Ongau, a UNU fellow in 2010, compared the time required to drill 12 directional wells from Kenya to 14 similar wells of regular diameter from Iceland. These selected wells have the same casing sizes but the Kenyan wells are deeper (Table 7). The wells have 9⅝" production casing and are directionally drilled to total depth with an 8½" bit. The Iceland wells are a subset of the 22 regular diameter wells analysed above and the time data for the Kenya wells is from drilling records and recorded KPI's.

TABLE 7: Depths of wells in Kenya and Iceland, regular diameter (Miyora, 2010)

Kenyan wells		**Icelandic wells**	
Steps	Depths (m)	Steps	Depths (m)
0	0-60	Surface casing	0-90
1	60-300	Anchor casing	90-300
2	300-1000	Production casing	300-800
3	1000-2800	Production liner	800-2300

Figures 7 and 8 show the results of a breakdown of drilling time for the Kenyan and Icelandic wells. Table 8 shows percentages of drilling time for both groups of wells. In Kenya a greater percentage is spent in drilling and changing of bits whereas relatively more time is spent on logging, cleaning and casing in Iceland.

The overall advance from start to finish of the drilling is about 58 m/day at Hengill vs. 48 m/day for Kenya. The workdays required to drill the average depth of the Kenyan wells of 2.767 m were 57.3 days in Kenya but 49.2 days in Iceland.

In both countries about 80% of the wells were drilled according to plans but 20% were "problem wells" mainly due to the rigs getting stuck and other geological risks.

TABLE 8: Breakdown of drilling time in percentages for similar wells in Kenya and Iceland (Miyora, 2010)

	Drilling	**Casing**	**Cem.**	**Plug**	**Stuck**	**Ream**	**Fish**
Kenya	57.94	4.42	7.40	0.47	1.26	3.22	0.42
Iceland	45.31	8.33	5.29	4.45	4.99	2.16	0

	Water	**bit/BHA**	**Repair**	**Cleaning**	**Logging**	**Other**
Kenya	0.37	9.55	2.02	1.66	4.93	6.35
Iceland	0.12	0.95	1.16	9.43	17.52	0.28

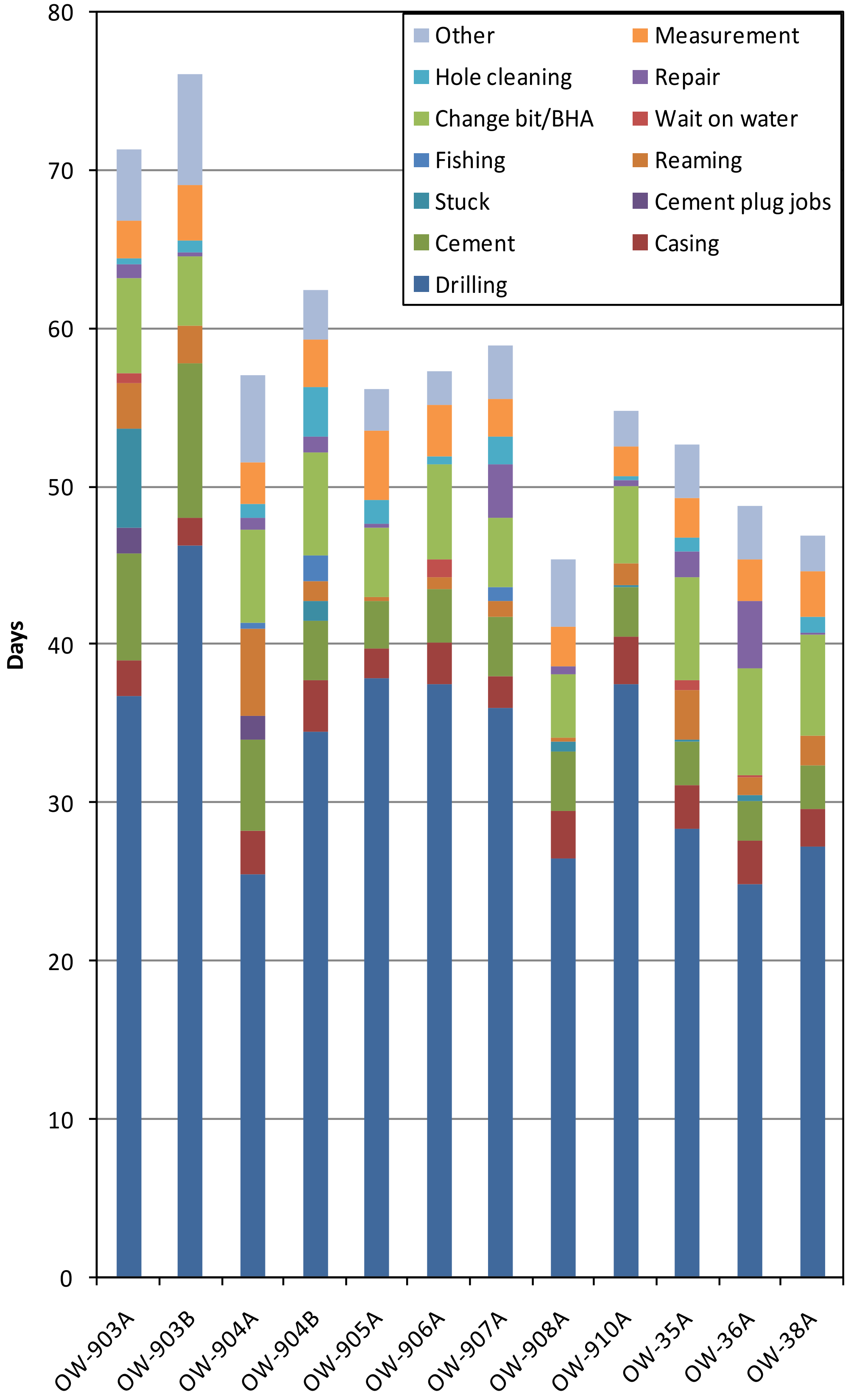

FIGURE 7: Time analysis for regular diameter wells in Kenya (Miyora, 2010)

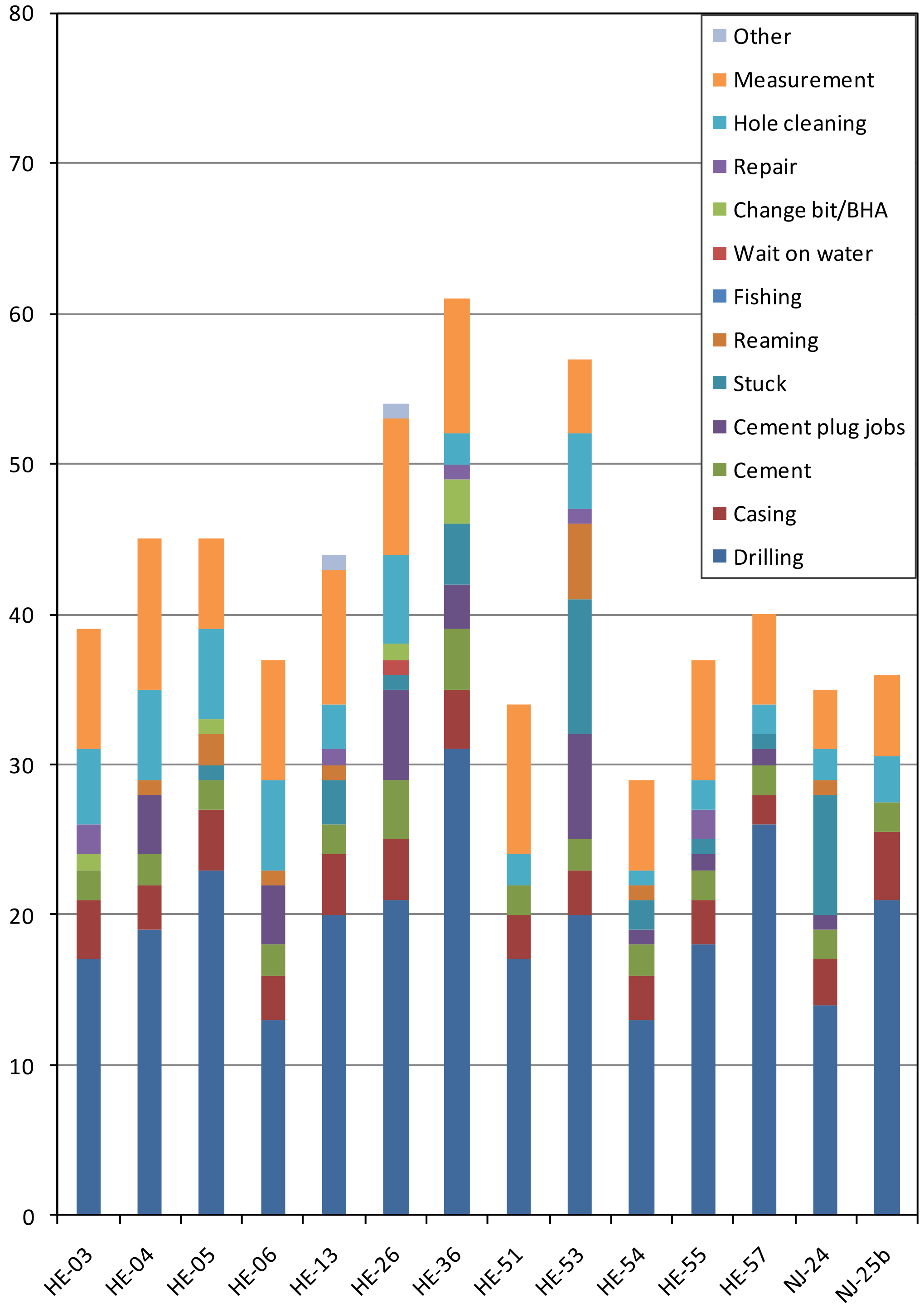

FIGURE 8: Time analysis for regular diameter wells in Iceland (Miyora, 2010)

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