

## **Case-Based Reasoning, a method for gaining experience and giving advise on how to avoid and how to free stuck drill strings.**

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### **Abstract**

Stuck pipe seems to be an unavoidable problem. Based on historical data every third well will experience stuck pipe, and various estimates indicates that associated costs exceeds 250 mill \$ per year for the industry. Since the problem is repetitive, a logical countermeasure is to store the data describing stuck pipe situations and implement procedures that reuse this information to solve similar problems when encountered. When a sufficiently large data base is created, it can be applied to analyse any new stuck pipe situation: How does the new situation (new case) compare to any of the previous cases and what was the solution to the most successful of them? What are the recommendations for the new case? If the new problem is solved, a new case can be created which supports the recommended solution, or if the solution is different, an additional case can be created containing new insight and experience. Along with the description of a case-based reasoning system implemented to study this problem, this paper also presents statistical material of stuck pipe incidents from an operator for the years 1990-1996, together with how this material was used to select the parameters for building a hierarchical knowledge model. A realistic case demonstrates the idea and how the overall system will help an operator to reduce downtime.

### **Introduction**

Based on data from 383 wells drilled in the Gulf of Mexico during 1981 - 1986, in which 105 incidents of stuck pipe occurred, Shivers and Domangue<sup>1</sup> showed that every 3.5th well experienced a stuck pipe incident. Valuable time is lost in trying to free stuck drill strings. A BP task force study<sup>2</sup>, involving 700 wells from the Gulf of Mexico and North Sea operations, found the average stuck pipe cost per well amounted to 170 000 \$ during 1985 - 1988, and represented 3 - 5 % of the total drilling costs. The cause of going stuck is related to human inability to grasp all the information pointing at the approaching problem. The BP study found that 40 % of stuck incidents occurred while the pipe was stationary and 50 % while tripping. Their study also pointed out that 57 % of the incidents occurred in the 4 hour period around crew change (2 hours before and after), meaning, after subtracting an average percentage of each 4 hour period, that 36 % of stuck pipe incidents can be related to crew change. In 1987 BP initiated an awareness campaign against stuck pipes involving handbooks, short courses involving field engineers, emphasising of co-operation and communication, competitions etc<sup>3,4</sup>. BP found that during 1989 and 1990 the costs were reduced by more than 50 % and the campaign left no doubt that human alertness was the main contributor to the problem. BP experienced that the motivation decayed 3 years after initiation of the campaign; from 1991 through 1994 the associated costs increased<sup>5</sup>. This was explained by the fact that less emphasis was placed on stuck pipe prevention, partly as a result of not having many problems, partly due to significant knowledge erosion. The message, training and awareness program was reinforced (1994), and stuck pipe costs are again falling.

Statoil initiated a similar program in 1991<sup>6</sup>. They saw a marked decline in stuck pipe expenses in 1992 and 1993, but although Statoil knew about the bouncing effect the cost of stuck pipe started to rise again 3 years after the program initiation as seen in Figure 1. Any campaign will inevitably loose its momentum with time, and the stuck pipe problem will increase towards its historical level. In 1993 the Dutch oil company NAM also initiated an awareness campaign<sup>7</sup> which resulted in a cost reduction of 54 % in 1994.

A supplementary method to attitude campaigns is active computerised support for information reuse, where particularly the method of Case Based Reasoning (CBR) has been found promising<sup>8</sup>. When a new stuck pipe problem is approaching, a CBR system will suggest, on the basis of a set of stored past experiences (i.e. cases), how to avoid, and if unsuccessful in avoiding, how to treat the problem. The first stage of the method has been completed<sup>9</sup>, but the full effect of the method is reached first in stage 3;

- Stage 1. Demonstration version
- Stage 2. Implemented as an advisory tool
- Stage 3. On-line surveillance, i.e. application of on-site drilling data

This paper describes only stage 1. An eventual success of stage 2 is based on the results of stage 1, but relies also on how the operator eventually will implement it in the drilling operation environment. Since the problem is largely related to how the driller and his crew reacts to a spectre of indicators, the human interaction with the system is vital for its success. But often field personnel do not have the incitement to communicate with computers, or they want things automated to the highest degree possible - provided reliability is ensured. Therefore stage 3 will be the ultimate stage, based on implementation of logical programmable transducers technology (LPC), but lies some years ahead.

The stuck pipe problem is like most problems a two part problem;

1. Detect a potential stuck pipe situation and attempt to avoid it
2. Free the stuck pipe whenever it is unavoidable

Part 1 is the most challenging and potentially the most rewarding part. As it is today, the parameters/operational data pointing at a possible problem are vague and difficult to sense and interpret by humans. However, the sensitivity can be increased in several ways. Examples are concentrate on those operational activities with risk of going stuck (like tripping and static pipe), or by focusing on critical hole sections (like the 12 1/4" section).

Freeing of a stuck pipe, on the other hand, takes a lot of time. If the driller has easy access to similar cases where the pipe was successfully freed, he may attack the problem optimally by reusing past experience and thus solve it quicker.

### **Case base reasoning (CBR)**

Before returning to the problem of warning, detection and freeing of stuck pipes we will briefly summarise the CBR methodology<sup>8,10,11</sup>. CBR is a kind of analogical reasoning, and consists of the following steps:

- a) Gather data.
- b) Detect a possibly approaching problem.
- c) Decide if gathered data are sufficient to define the situation as a new problem. If not;
- d) Perform additional examinations (i.e. check drag, check circulating pressure etc.).
- e) Search the case base for similar past cases.
- f) Generate a set of the most likely stuck pipe hypothesis and present a set of possible solutions in descending order to the current problem.
- g) Interact with user to select the best hypothesis. Generate a detailed Òto-doÓ list.
- h) After the case has been solved, the case base can be updated with data from the situation just experienced. The new case will contain information about whether the pipe was successfully freed or not, and depending on this it will be used differently in the future, i.e. to help solving a new problem or avoid repeating previous mistakes respectively.

The CBR system thus consist of several modules<sup>6</sup> as shown by the steps a) through g) above and a corresponding set of operations as seen from Figure 2.

Two of the modules in the CBR-system are the General Knowledge module and the Case Base.

### **The General Knowledge module**

In order for the CBR-system to be able to reason, there must exist logical relations between the parameters involved in the drilling process, and information on to what degree the parameters are deviating from normal (and as such a potential cause of the stuck pipe situation).

The knowledge module consist of at least four information types as shown in Figure 3. These are:

- ¥ Type of activity
- ¥ Material (equipment and process material)
- ¥ Logical object (facility, person)
- ¥ State
  - ¥ Measured parameter (findings)
  - ¥ Non observable parameters
  - ¥ Solution
    - Failure
    - Repair
    - Outcome (end state)

Type of actual activity will be related to a set of measured parameters or findings, and when, depending on type of activities, may indicate or point to a possible failure type (stuck pipe types). An important notion in identifying a failure mode is the notion of a non observable parameter state, i.e. a system condition that is not directly describable by measured parameters (or findings). Non observable parameter states are general system states that are neither findings nor end state situations, they are not measurable or observable at the surface, and they are usually related to conditions in the open hole. An important reasoning task is to relate findings to possible non observable parameters or end states, using the knowledge model, then check expected findings and relate these findings to other measured findings until a set of possible stuck pipe modes is suggested.

A more detailed list of non observable state parameters are presented in Figure 4. Non observable state parameters can be investigated by stopping the drilling operation in order to perform suitable tests, i.e. determining if the torque or drag is deviating from the normal background level. Some intermediate parameters can be elevated into measured parameters (findings) if recorded by measurement while drilling (MWD) tools<sup>12</sup>.

Relationship between parameters in the knowledge module are interconnected through structural, casual, mathematical or statistical relations. These relationships are exemplified below:

#### 1. Structural or general inheritance links:

- ¥ type of operation has subclass (hsc) tripping (the inverse: is subclass of).
- ¥ clay has instance (hi) soft (inverse: is instance of).

After having formed the inheritance module the parameters may be additionally interconnected in several ways, e.g. via;

#### 2. Causal relations:

- ¥ ledges causes high drag (inversely; is caused by)
- ¥ water based mud (WBM) enables swelling (inversely: enabled by)

#### 3. Mathematical relationship.

Such expressions are implemented as functional expressions, e.g.:

$$F_{\text{diff.stuck}} = f * \Delta p * A$$

$$f_{\text{sliding}} = (F_{\text{pull}} - F_{\text{static}}) / F_{\text{static}}$$

A spotting fluid with low viscosity over the range of applied shear rates will penetrate the pipe/mud cake interface<sup>13</sup> and thereby reduce the friction factor, f. The force, F, to free the pipe will grow almost linearly with elapsed time after stuck. This is shown through practical tests and through data gathered by BP<sup>5</sup>, but not yet implemented in our model.

#### 4. Statistical relationship - building the knowledge model.

Statistical material from Stuck pipe situations, altogether 75 incidents, encountered by Statoil during 1991 - 1996 are presented in Figures 5 through 10. In the knowledge model statistical information has

been introduced by weighting the strength of relationships. Frequent incidents cause respective relationship to be weighted with 1.0, 0.9 or 0.8, while weak relationships are weighted by 0.1, 0.2 or 0.3. The "explanatory strength" of each relationship can thus be modelled.

*Statistics of situations before going stuck:*

Figures 5 and 6 show that stuck pipe occur most often when drilling the 12.25" hole section and during running the string/casing/liner. The most frequent observations made just prior to going stuck, seen in Figure 7, is increased drag (33 times) or reduced weight (14 times), while the most problematic stuck incidents are related to those where increased torque and lost circulation is observed.

*Statistics of the situation after going stuck:*

Observations made after stuck, listed in Figure 8, may help deciding which freeing method that should be applied. The freeing methods applied by Statoil is shown in Figure 9, where also the average duration of each incident is shown. Based on observations after stuck and remedial work it was possible to identify, with some degree of certainty, the reason for going stuck as presented in Figure 10, together with average time consumption pr. incident.

Based on structural, causal, mathematical and statistical material we have constructed a complex Knowledge model as indicated in Figure 3 and 4. Only selected examples of relations between the parameters are shown in this figure, while all relations are implemented in the CBR simulator.

## Cases

A case consists of a set of parameters, relations between them and a detailed description of the solution. In Figure 11 case no 18 is deciphered from the data base and presented in understandable language<sup>14</sup>.

## Discussion

The ability to predict and suggest preventive measures will be the most awarding result of this tool. If for instance hole cleaning is found to be the problem, the program will suggest a priority list of actions to improve hole cleaning; e.g.

- Tandem pills (high/low viscosity)
- Reaming / rotating
- Turbulence in annulus

It is important that the program can build its cases on reliable background data; the normal level of the parameters must be determined, and any deviation will be compared to this normalized background level. A procedure involving "normal" drag/torque measurements must be implemented.

In the next phase of the project the tool will be tested out as an advisory tool where emphasis will be put on choice of remedies after stuck. The last stage, in which the tool is integrated with online variables, will predict stuck strings, based on the technology described above.

If the MWD tool is equipped with downhole WOB and torque, the average friction factor can be estimated and monitored during all drilling phases, in sliding and rotating (or both) mode, on or off bottom<sup>12</sup>. Trends (different for each drilling phase) and deviations from them will give an early warning of sticking<sup>15, 16</sup>. The same technique (limited to drag) has been successfully applied by NAM<sup>7</sup>.

## Conclusions

Based on the study reported in this paper, some of the conclusions drawn were:

1. Stuck drill string is a serious problem. This type of problem costs the oil industry world wide approximately 250 mill. \$ every year due to wasted time.
2. Stuck pipes are mainly resulting from differential sticking (25 %), packed hole (42 %) or jammed pipe (20 %). Stuck pipe occurs predominantly during tripping/reaming (56 %) or while the drill string was stationary (30 %), and third most likely during steady drilling operations(14 %).
3. The problem is related to alertness of the people involved in the operation, and the alertness is positively effected by attitude campaigns. Decay of campaigns also leads to a decay of the alertness, and the stuck problem soon returns to its historical level.
4. Case Based Reasoning (CBR) has been suggested to take over the reminding task. However, its success will largely depend on utilization of artificial intelligence and on how operators eventually will implement the method into the drilling operation.
5. CBR is still at its early childhood in the petroleum industry. When available to the operator, reduction in down time caused by stuck pipe is expected.

### **Acknowledgement.**

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Table 1. Break down of stuck pipe incidents by type of stuck and type of operation.

Investigation	Type of sticking						Type of operation			
	Diff.stuck	Mechanical stuck			Salt	Junk	Other	Trip	On bottom	Static
Bottom Static Other		Packed	Jammed							
BP North Sea <sup>1</sup>	23	37	21	14	-	5	45	10	42	3
BP Gulf of Mexico <sup>1</sup>	40	36	24	-	-	-	52	12	34	-
Statoil North Sea <sup>4</sup>	16	70	11	-	-	3	65	20	15	-
NAM <sup>9</sup>	23	26	25*	-	5	9	63	-	-	-
Average	25	42	20				56	14	30	

\* Hole instability & geometry related

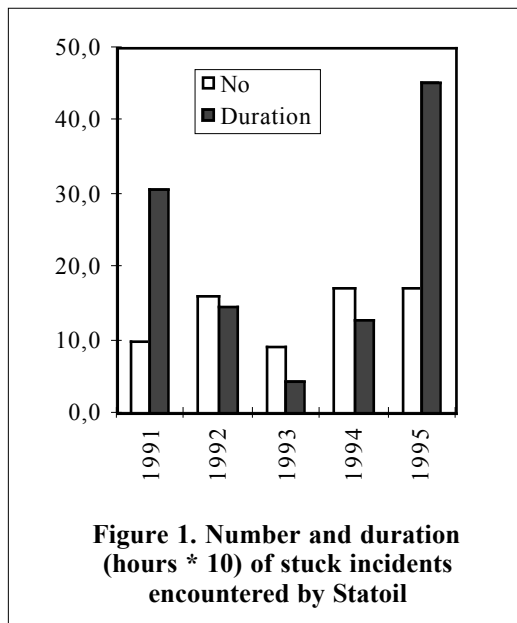


Figure 2. The CBR cycle<sup>6</sup>

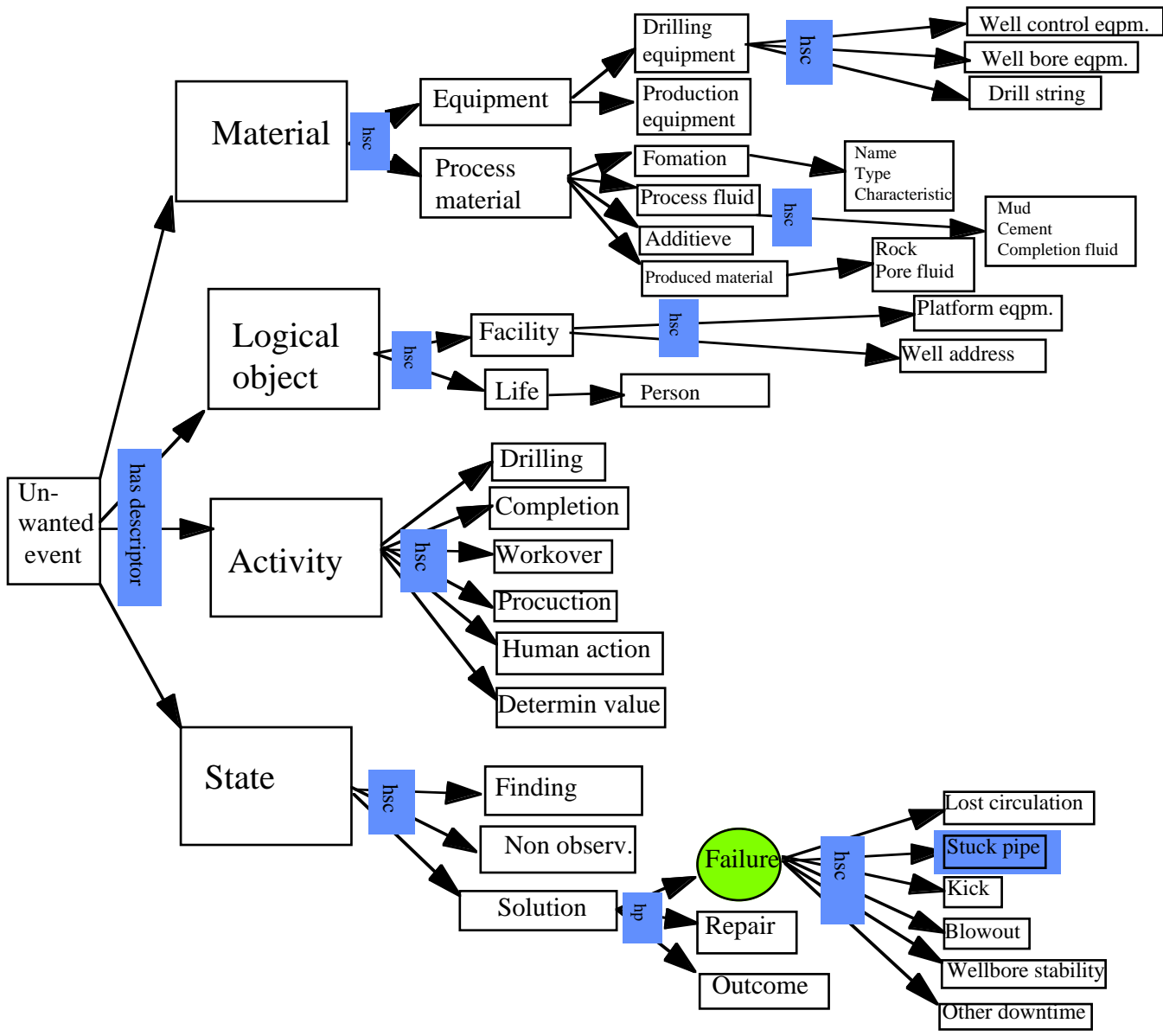


Figure 3. A simplified knowledge mode (structural form)

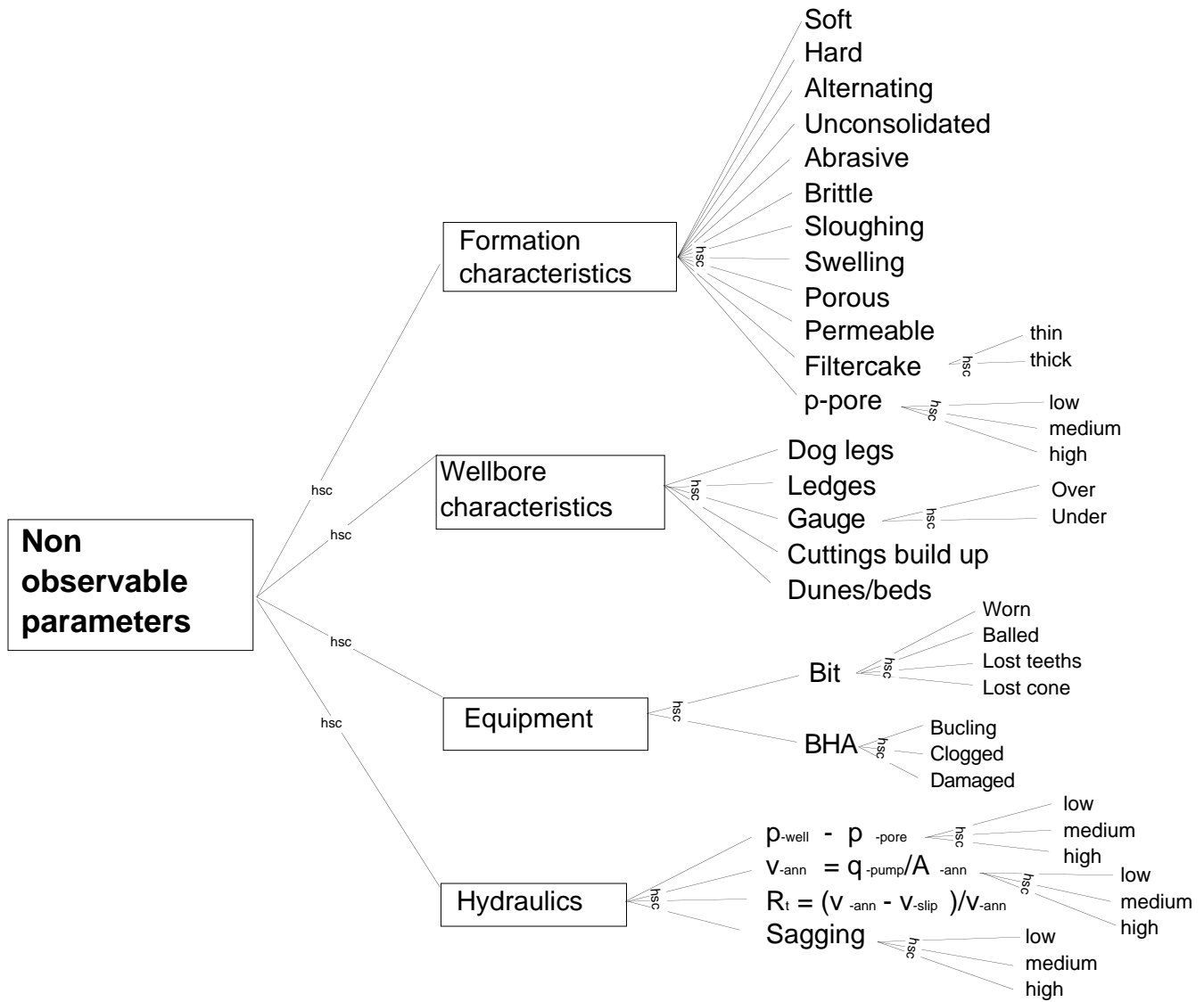
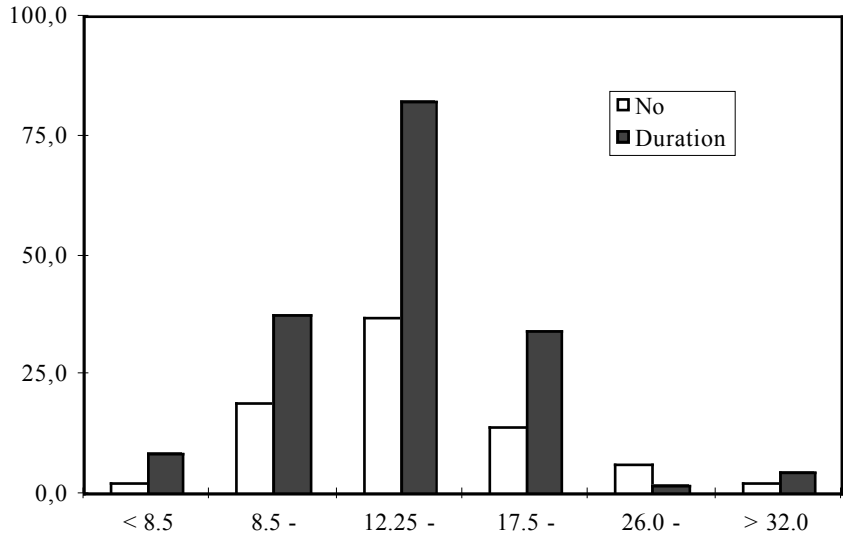
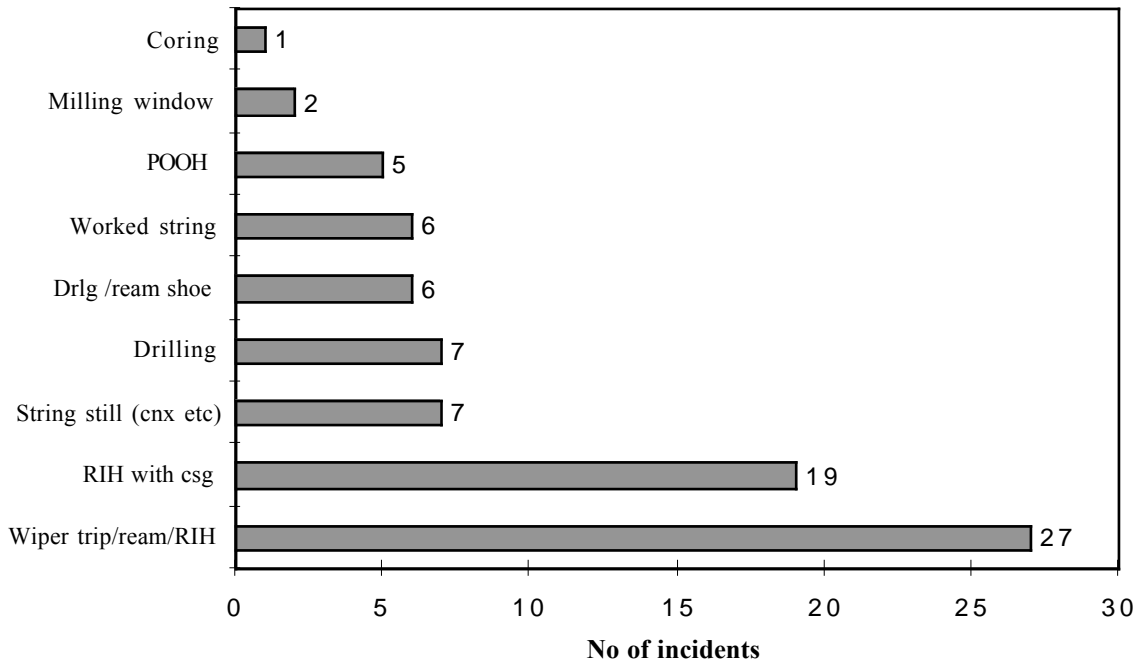


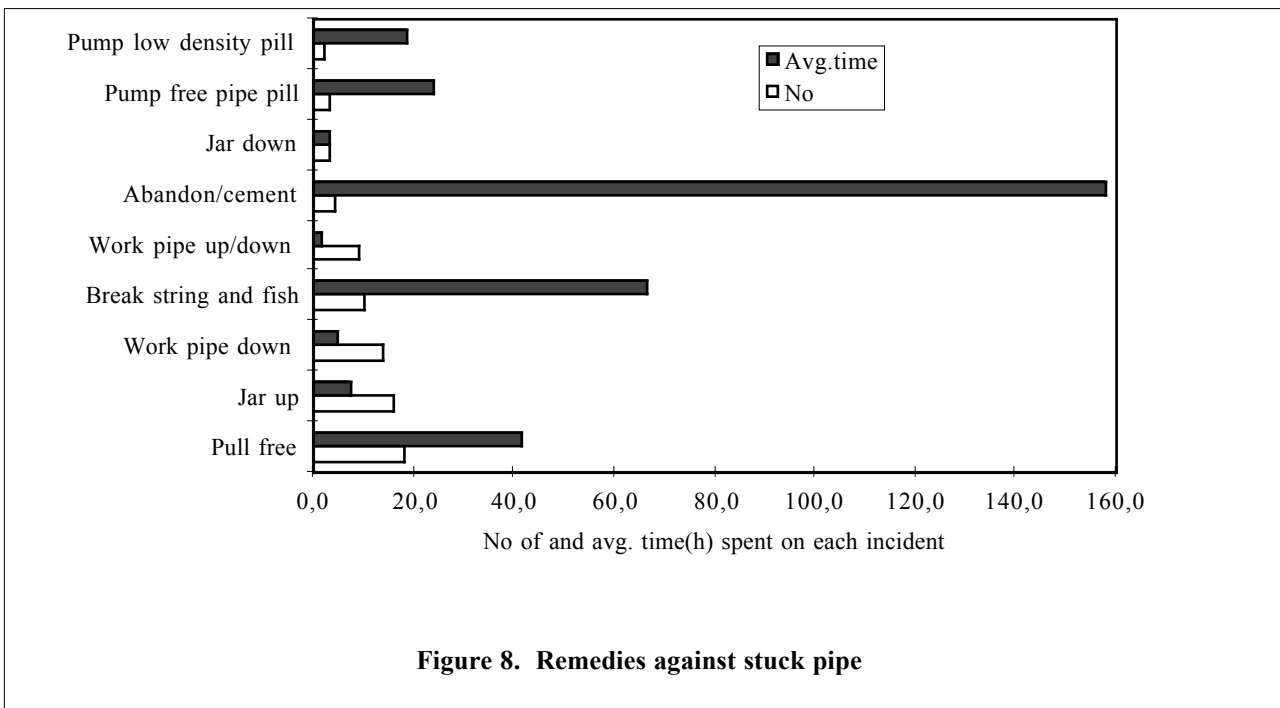
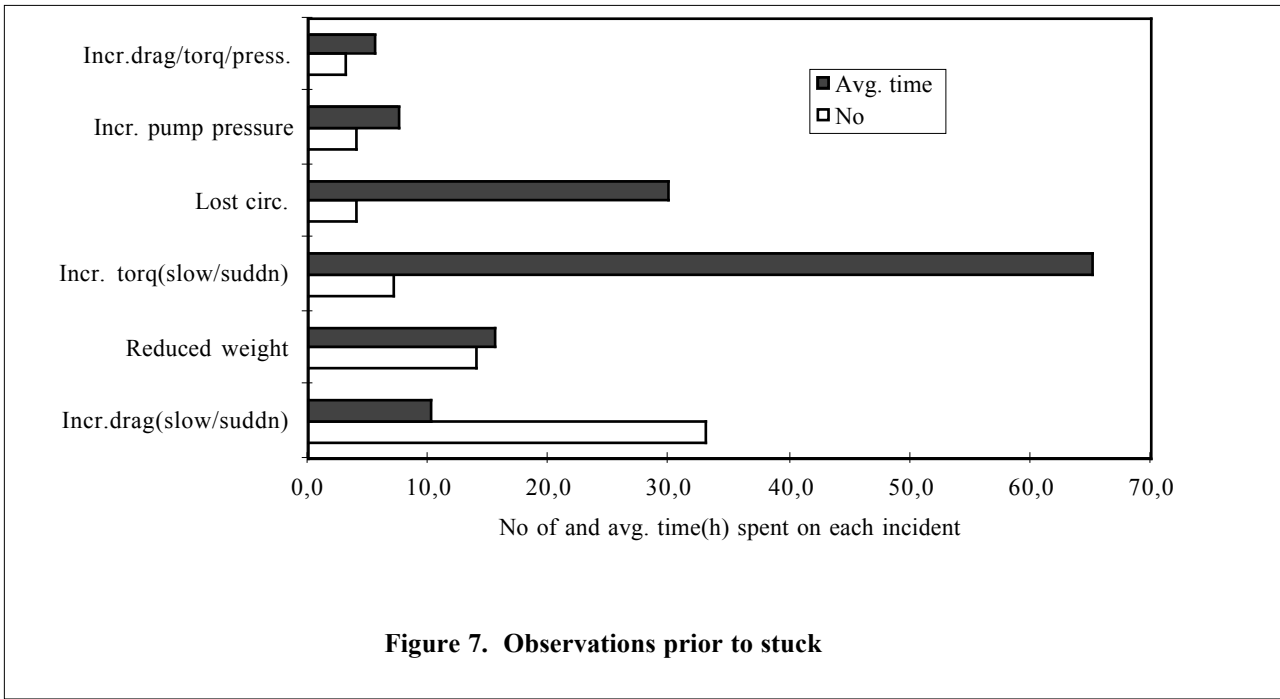
Figure 4. State of non observable parameters. The drilling process may be stopped to further investigate these parameters if necessary.

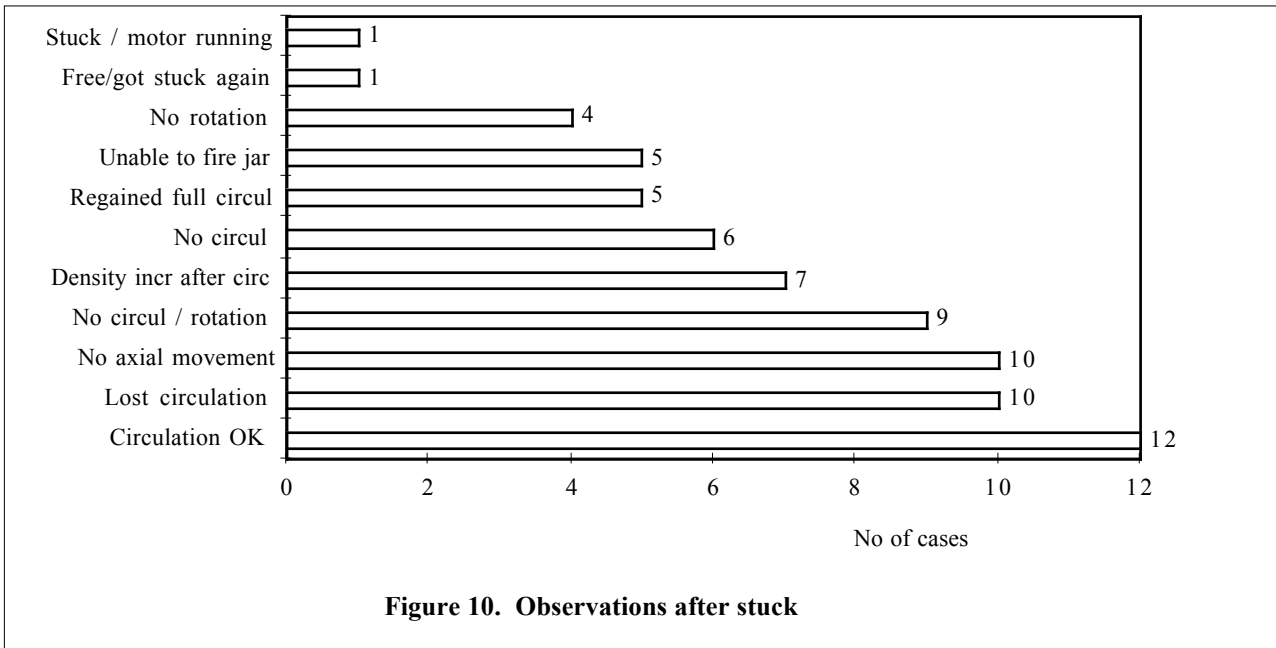
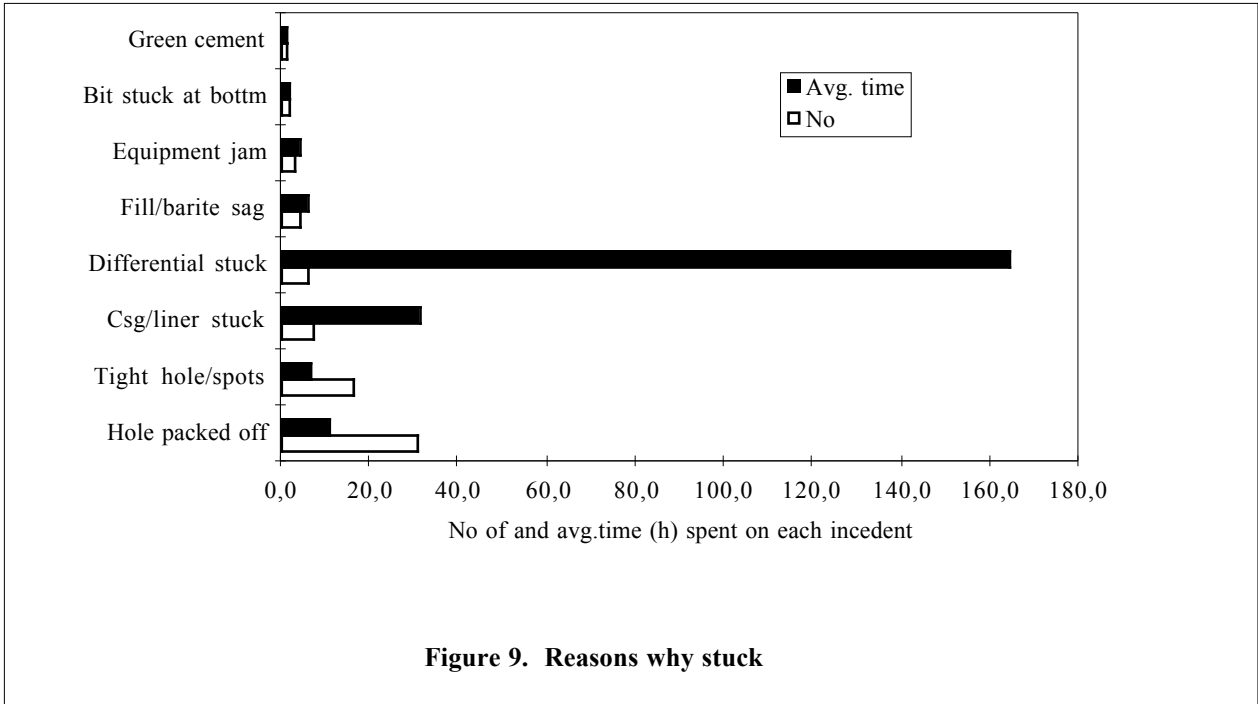


**Figure 5. Number and duration (h \* 10) of stuck incidents as function of hole size (in)**



**Figure 6. Operations prior to stuck. POOH=pull out of hole. RIH=run in hole**





**Heading** Mechanical stuck during a wiper trip

**Task** Solve a new stuck pipe incident

**Situation Identification**

Well no:	0033/09-C18	Water depth (m):	145.8
Well type:	Production drilling	Last csg. (in):	13 3/8
Field:	Statfjord	Depth csg.shoe (m MD):	2116.7
Platform:	Statfjord C	Bit size (in):	12 1/4
Spud date:	23.01.95	Total depth (m MD):	4005.3
Date of stuck:	15.02.95	Total depth (m TVD):	2902.4

**Findings or observation**

<u>Operational:</u>	<u>Drilling fluid:</u>	<u>Equipment:</u>	<u>Wellbore:</u>
Torque erratic	ANCO 2000	BHA no. 13	ID = 12.25"
Drag increasing	Density =1.32	LBHA = 122 m	I = 64 degrees
WOB normal	600 = 70	ODDP = 5"	A = 127 degrees
RPM + 8 %	300 = 51		Form.press = 1.30 S.G.
ROP/dc - 14 %	200 = 40		Form.type =
q-pump + 5 %	100 = 28		clay,sandstone, coal
p-pump + 20 %	v <sub>ann</sub> = 2.2 ft/s		layers
	v <sub>slip</sub> = 1.2 ft/s		

**Solution**

**Failure type** Mechanical stuck - reactive formation

**Initial path** Axial movement : no  
 Rotation : no  
 Circ./pressure : normal/increased

**Repair action**

- With reference to previous related experience (Case 2, 18, 29 and 102) the most probable methods of successful freeing of the pipe were (in priority order):
1. Work pipe down (take advantage of gravity) immediately (take advantage of time aspect), then circulate.
  2. Pump down low gravity pill + free pill and start jarring down.

**Outcome or Failure state**

The pipe was worked free after only 1 h of downward movements. Case 2 and 102 were thus strengthened.

**Explanation**

Hole instability caused stuck pipe (mechanical related). The shale section (which had high smectite content) with alternating sand layers became de-stabilised chemically (mud possessed low inhibiting properties). In addition streaks of coal layers (very weak) caused wall failure. The wellbore failure mechanisms were also combined with collapse due to low mud weight and direction of hole (azimuth) vs. maximum horizontal stress.

High hole inclination further strengthened the indication pointing towards hole instability-related stuck problems, both with respect to the mechanical and chemical origin.

*Figure 11. Case no 18 (a constructed case).*