A NOVEL PC PROGRAM FOR DRILL STRING FAILURE DETECTION AND PREVENTION BEFORE AND WHILE DRILLING SPECIALLY IN NEW AREAS

Shokir E. M. El-M.

King Saudi University, College of Engineering, Petroleum Department
P.O. Box 800, Ryiadh 11421, Saudia Arabia, Abul-Hamd, I., Gulf of Suez Petroleum Company (Gupco), and El-Tayeb, S., Cairo Univeristy, Petroleum Department

Abstract

Drill string failure is due to a lot of reasons, which may occur either individually or in-group. In order to prevent or at least minimize occurring drill string failure, all reasons should be recognized. To do that, one should have a good designed approach to test all factors, affecting drill string failure, to early eliminate the problem. Early studied cases were analyzed without an overall approach and without revealing the actual reasons of the drill string failure.

This paper introduces a new interactive program that helps to recognize and prevent the drill string failure before and while drilling. The validity of this program is successfully approved by its application on some failure cases. Therefore, it could be successfully applied in other cases, and easier recognized if the drill string is close to fail and hence an immediate action is to be taken to improve the drilling parameters to prevent the drill string failure.

1 Introduction

Drillstem failures, even such routine failures as drill pipe washouts, can contribute significantly to the cost to drill today's wells. These costs grow exponentially when the failure results in fishing operations, and in extreme cases, failures can even cause well-control problems [1]. In a 1985, McNalley [2] reported that 45% of deep well drilling problems were related to drill string failures. Moyer and Dale [3] concluded that drillstem separations occurred in one in seven wells and cost an average of $106,000. For such routine failures as drill pipe washouts, the failure often is accepted as “part of the business”. The offending components are replaced and operations are resumed. If the cause of failure is unusual, analysis must performed, the results should be reported and recommendations are made to prevent similar failures. These failures seem to be handled case – by – case without an overall approach to prevention. Therefore, the aim of this study is to introduce a new broader programing methodology to recognize and prevent the drill string failure before and while drilling. The validity of this methodology is tested by its application on some failure cases. In order to achieve this goal, the following procedure is applied through this work:

- Designing the mathematical algorithm and a computer program using a Visual Basic for predicting and preventing drill string failure before and while drilling, by considering the causes of drill string failure that may occur in different situations.
- Testing the devolped program by its application on some failure cases.

2 Mathematical and logical Algorithm

2.1 Dogleg Severity

Maximum dogleg severity can be obtained from the directional survey sheet of the well
Determine the permissible dogleg severity by using the following Equation [4]:

$$k = \frac{432{,}000\sigma_b \tanh L\sqrt{T_n / EI}}{\pi EDL\sqrt{T_n / EI}} \qquad \text{.......(1)}$$

The maximum permissible bending stress (σ_b) is calculated from the buoyed tensile stress (σ_t) for grades E & S pipe by using the following Equations [4]:

$$\sigma_{bE} = 19{,}500 - \sigma_t(10/67) - \left[(\sigma_t - 33{,}500)^2\left(0.6/(670)^2\right)\right] \qquad \text{.......(2)}$$

$$\sigma_{bS} = 20{,}000(1 - \sigma_t / 145{,}000) \qquad \text{.......(3)}$$

where:

K : maximum permissible dogleg severity, degree/100ft
E : young's modulus, psi=30 x 10^6
D : drill pipe outside diameter, inch
L : half the distance between the tool joints, inch
I : drill pipe moment of inertia = $(\pi/64)(D^4 - d^4)$, inch
D : drill pipe inside diameter, inch
σ_{bE} : maximum permissible bending stress for grade E pipe, psi
σ_t : buyed tensile stress, psi = T_n / A
T_n : tension load below the dogleg, lb
A : cross-sectional area of drill pipe, inch^2
σ_{bS} : maximum permissible bending stress for grade S pipe, psi

If the resultant well dogleg is greater than the permissible dogleg, failure may occur. *Else*, check the next item.

2.2 Operating Torque

Determine the twist angle for drill pipe, heavy weight drill pipe, and drill collar by using the following Equation [5]:

$$\theta / L = T / JG \qquad \text{.......(4)}$$

Where:

θ / L : angle of twist (radians/inch)
L : length of drill string
T : torque, ft-lb

G : modulus of rigidity, psi =12 x10^6

J : polar moment of inertia, inch^4

J can be calculated for drill pipe and drill collar from the following Equations [4]:

$$J = \frac{(J_{Body} J_{Joint})}{[0.95 J_{Joint} + 0.05 J_{Body}]} \quad \text{...(5)}$$

For drill pipe:

$$J_{Body} = \pi / 32 \left[(OD_{Body})^4 - (ID_{Body})^4 \right] \quad \text{...(6)}$$

$$J_{Joint} = \pi / 32 \left[(OD_{Joint})^4 - (ID_{Joint})^4 \right] \quad \text{...(7)}$$

For drill collar:

$$J = \pi / 32 \left[(OD_{Body})^4 - (ID_{Bodyt})^4 \right] \quad \text{...(8)}$$

If the operating torque exceeds the make-up torque, the angle of twist will be greater than the calculated angle of twist and hence failure may occur. *Else*, check the next item.

2.3 Bottom Hole Assembly Length

By knowing the designed maximum weight on bit from the bit specifications, using HWDP as transition stiffness between drill collar and drill pipe is recommended. Determine the length of the heavy weight drill pipe (HWDP) as following [6]:

$$L_{HWDP} = \left[\frac{(WOP)(DF_{BHA})}{(K_B)(Cos\theta)} - (L_{DC} W_{DC}) \right] \frac{1}{W_{HWDP}} \quad \text{...(9)}$$

Where:

L_{HWDP} : minimum length of HWDP section, ft

WOB : maximum weight on bit, lb

DF_{BHA} : design factor for excess BHA weight =1.15

L_{DC} : minimum length of drill collar section, ft

W_{DC} : air weight of drill collar, lb/ft

W_{HWDP} : air weight of HWDP, lb/ft

K_B : buoyancy factor

θ : maximum hole angle at BHA, degree

If the designed length of the heavy weight drill pipe is less than the calculated HWDP, the neutral point will be in the drill pipe and hence failure may occur, so, adjust the length of the HWDP to bring the neutral point below the drill pipe. *Else*, check the next item.

2.4.Connection Make-Up Torque

Determine the revised make-up torque by using the following Equation [6]:

Revised MUT=MUT x friction factor of dope……………………………………………………(10)

If the connection make-up torque is less than the revised MUT, failure may occur. *Else*, check the next item.

2.5 Revolutions Per Minute (RPM)

Critical rotation speeds in drill pipe strings which cause vibrations are often the cause of crooked drill pipe, excessive wear, and fatigue failure. Critical speeds will vary with length and size of drill string and hole size. Two types of vibration may occur, nodal vibration as the pipe may vibrate in nodes as a violin string. The second type of vibration is axial vibration as the pipe may vibrate as a pendulum.

2.5.1 Noda Vibration

Determine the critical RPM by using the following Equation [7]:

$$RPM_n = \frac{33056\sqrt{OD^2 + ID^2}}{S^2} \qquad (11)$$

Where:
RPM_n : critical speed, revolutions per minute with nodal type
D : outside diameter, inch
d : inside diameter, inch
S : length of one joint of pipe, feet

If the drilling RPM is equal to the calculating the critical RPM_n for drill pipe, heavy weight drill pipe, and drill collar, failure may occur, hence the drilling RPM should be chosen to lower than the RPM_n.
Else, check the next item.

2.5.2 Axial Vibration

Determine the critical RPM by using the following Equation [8]:

$$RPM_a = 258{,}000 / L \qquad (12)$$

Where:
RPM_a : critical speed, revolutions per minute with axial type
L : total length of string, feet

If the RPM is equal to RPM_a and/or equal to the harmonic vibration, failure may occur. *Else*, check the next item.

2.5.3 Depth of Harmonic Vibrations

Determine the depths of harmonic vibrations coincide by using the following Equation [8]:

$$L = \frac{258{,}000 Xi^2}{N}, \text{ I = 1,2,3 ….etc} \qquad (13)$$

Where:

N : drilling speed, RPM

When the drilling depth equal the calculated depth of harmonic vibrations, failure may occur. The drilling RPM should be lower than RPM_a. *Else*, check the next item.

2.6 String Buckling

Buckling occurs when compressive axial forces exceed a critical buckling force. The critical buckling forces can be found in the sinusoidal buckling and helical buckling. If the compressive force exceeds that of either the sinusoidal or helical buckling, the string is buckled [9,10].

2.6.1 Sinusoidal Buckling: (for build Section)

Determine the sinusoidal buckling force by using the following Equation [9,10].

$$F_s = (2EIK/r) + 2\sqrt{(EIK/r) \; + [(EIK\sin(\alpha)/r)]} \qquad (14)$$

Where:

F_s : compression force of sinusoidal buckling, lb

F_H : compression force of helical buckling, lb

I : moment of inertia for component, inch4

E : young’s modulus of elasticity, psi

W : tubular weight in mud, lb

Inc : wellbore inclination, degree

K : curvature in the vertical plane (build or drop), degree/100ft

R : radial clearance between wellbore and component, inch

2.6.2 Sinusoidal Buckling: (for Drop Section)

Determine the sinusoidal buckling force by using the following Equation [9,10] :

$$K_{test} = \sqrt{rw\sin(\alpha)} / EI \qquad (15)$$

IF ($K \geq K_{test}$) then,

$$F_s = (2EIK/r) - 2\sqrt{(EIK/r) \; + [(EIK\sin(\alpha)/r)]} \qquad (16)$$

IF (K < K_{test}) then,

$$F_s = -(2EIK/r) + 2\sqrt{(EIK/r) \; + [(EIK\sin(\alpha)/r)]} \;\ldots\ldots\ldots(17)$$

2.6.3 Helical Buckling:

Determine the critical buckling force by using the following Equation [11]:

$$F_H = 2.828427\ F_s \ldots\ldots\ldots(18)$$

2.6.4 Axial Force

Determine the axial force by using the following Equation [12] :

$$F_{axial} = \left[W_{air} Cos(\alpha) + F_{drag} + \Delta F_{area}\right] - F_{bottom} - W_{WOB} + F_{BS} \ldots\ldots\ldots(19)$$

Where:

Wair : weight of drill string in air, lb

Inc. : wellbore inclination, degree

F_{bottom} : a compression force due to fluid pressure applied over the cross sectional area of the bottom component

$F_{tension}$: tension pressure force, lb

F_{area} : change in force between bottom pressure force and tension pressure force

W_{WOB} : weight on bit, lb

F_{BS} : buckling stability force, lb

Where, (-) sign for compression and (+) sign for tension, and

$$External\ \ pressure = annulus\ \ surface\ \ pressure + annulus\ \ pressure\ \ gradient \times TVD \ldots\ldots\ldots(20)$$

$$Internalpressure = string\ \ surface\ \ pressure + string\ \ pressure\ \ gradient \times TVD \ldots\ldots\ldots(21)$$

If the calculated axial force is greater than the sinusoidal buckling force, the drill string may be buckled and hence failure may occur. *Else*, check the critical buckling force.

If the calculated axial force is greater than the helical buckling force, the drill string may be buckled and hence failure may occur. *Else*, check the next item.

2.7 Stifness Ratio

The connection of large drill collars to limber components should be avoided to reduce then risk of fatigues in the limber components. So, stiffness ratio which is given by Equation (22) should be limited and maintained less than 3.5 [13].

$$SR = D_s (D_1^4 - d_1^4)/(D_s^4 - d_s^4) \ldots\ldots\ldots(22)$$

Where: D_1 and d_1 are the outside and inside diameters for the large tool in inch, respectively, and D_s and d_s are the outside and inside diameters for the small tool in inch, respectively.

If the value of the stiffness ratio is greater than 3.5, failure may occur. *Else*, check the next item.

2.8 Connections of the Drill Collars

The following Table shows the connection types for drill collars that should be used to increase the fatigue limit up to 40% [14].

Table 1 Enhanced connection types for drill collars.

Drill Collar Size	Connection Type	Enhanced connection Type to Increase Fatigue limit up to 40%.
8 inch	6.625 inch Regular	NC-56
9inch	7.625 inch Regular	NC-61

2.9 Connection Threads Form

If the threads form of the connection with small radius root such as API IF (V-0.065), failure may occur. Thread form with full/large radius root such as APINC (V-0.038) should be used instead of the obsolete API IF (V-0.065) [15] . *Else*, check the next item.

2.10 Hole Size

If the hole size is 12.25-inch with long section, failure may occur. 12.25-inch hole section should be minimized as possible and set the casing to change the hole size to 8.5-inch to use bottom hole assembly configuration with a stiffness ratio less than or equal to 3.5. Else, check the next item.

2.11 Formation Type

If the formation drilled is salt, anhydrite, limestone or abrasive sand, failure may occur. *Else*, check the next item

2.12 History of the Drill String

If the history of each component of the drill string (problems exposed to the drill string, formation types that drilled with the drill string and how much times the drill string was exposed to the critical operations) is not known before using in the hole , failure may occur.
Else, check the next item

2.13 Drilling Fluid

If using water base mud for drilling the well with PH value less than 10 , failure may occur due to the high corrosive agent of mud [16]. So, using oil base mud instead of water base mud is the best solution to prevent failure if there is no problem concerning environmental constraints.
Else, check the next item.

2.14 Critical Events

- Pulling and Jarring on stuck pipe.
- Back reaming with high drag.

- High torsional drag.
- High tensile drag.
- Plugged drill pipe or plugged Bit.
- Enlarged hole at BHA.
- Slip cuts.
- Internal drill pipe pressure that exceeds drill pipe tube yield strength.
- Exceed maximum weight on Bit.
- Over torque and /or under torque on connections.
- Weld on down hole equipment.
- Under gauge hole.
- Wrong weight / grade of pipe in hole.
- Running bent pipe.
- Erratic Torque and drag.
- Running drill string with unknown history.

If the previous critical events occurred, failure may occur. These events should be strictly avoided.
Else, check the next item.

2.15 H_2S Concentration

Using oil base mud can minimize corrosion and sulfide stress cracking. Corrosion does not occur if metal is completely enveloped and wet by an oil environment that is electrically nonconductive. Oil base mud contains surfactants that stabilize water as emulsified droplets and cause oil wetting of the metal. Agents that cause corrosion in water (dissolved gases, dissolved salts, and acids) do not damage the oil-wet metal. Therefore, under drilling conditions that cause serious problems of corrosion damage, erosion-corrosion, or corrosion fatigue, drill string life can be greatly extended by using an oil mud. Hence, If H_2S is present in the formation being drilled, failure may occur. So, minimize that effect by using H_2S scavengers, use over balance drilling technique, and use oil base mud.
Else, check the next item.

2.16 Handling Practices

- If the following Handling practices of the drill string are not applied, failure may occur. These instructions should be applied to extend the drill string life that are:
- Protect drill string with thread protectors.
- Check drill pipe for straightness on the rack.
- Visually check box and pin for damage on the rack.
- Keep pipe set back area clean.
- Don’t hammer on drill pipe.
- Clean and inspect tong and slip dies frequently.
- Always use two tongs to make-up and breakout connections.

– Ensure that tongs are 90° angle in 2 planes when torque up connections.
– Don't let slips ride the drill pipe.
– Stop pipe, set slips gently, lower pipe slowly to prevent slip damage.
– Use the specified slips for each pipe size.
– Dope boxes, pins and shoulders generously.
– Monitor both make-up and breakout torque.
– Prevent shoulder damage from elevators.

2.17 Drill String Inspection

The following inspection schedule should be followed to reject the bad component early [17].

- ***Inspection schedule for drill pipe***:
  a. For hard rock: 1500 - 2000 Hrs or 50,000 - 5,000 ft
  b. b. For soft rock: 1500 - 2000 Hrs or 75,000 - 100,000 ft
- ***Inspection schedule for bottom hole assembly:***
  - o ***For hole size < 6.5 inch***
    a. For hard rock: 200 - 400 Hrs.
    b. b. For soft rock: 225 - 500 firs.
  - o ***For hole size > 6.5 inch***
    a. For hard rock: 150 - 300 Hrs.
    b. b. For soft rock: 200 - 400 Hrs

3 Computer Program

A computer program is created to apply the developed Logical Algorithm on any failure case and on any well while drilling to detect and diagnose all the factors, which may cause drill string failure with few time and less effort. The program is designed using the Visual Basic Language.

3.1 Program Name Screen

The first program screen includes the program name, designer name, program version, and a warning message for copyright program (Fig.1).

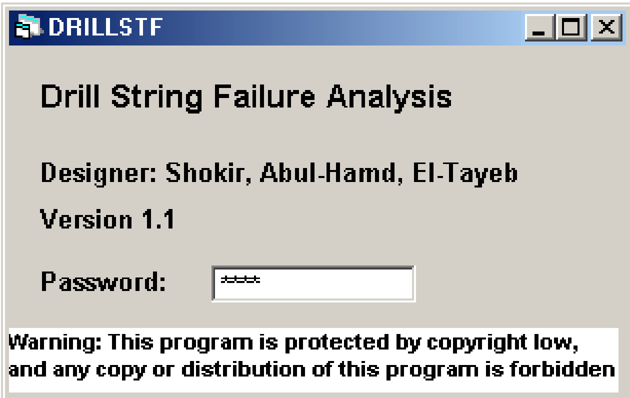

Fig.1 Program name screen

3.2 Input Data Screen

The input or required data are obtained from the drilling and geological reports, and reference API RP7G and inspection report (Fig. 2).

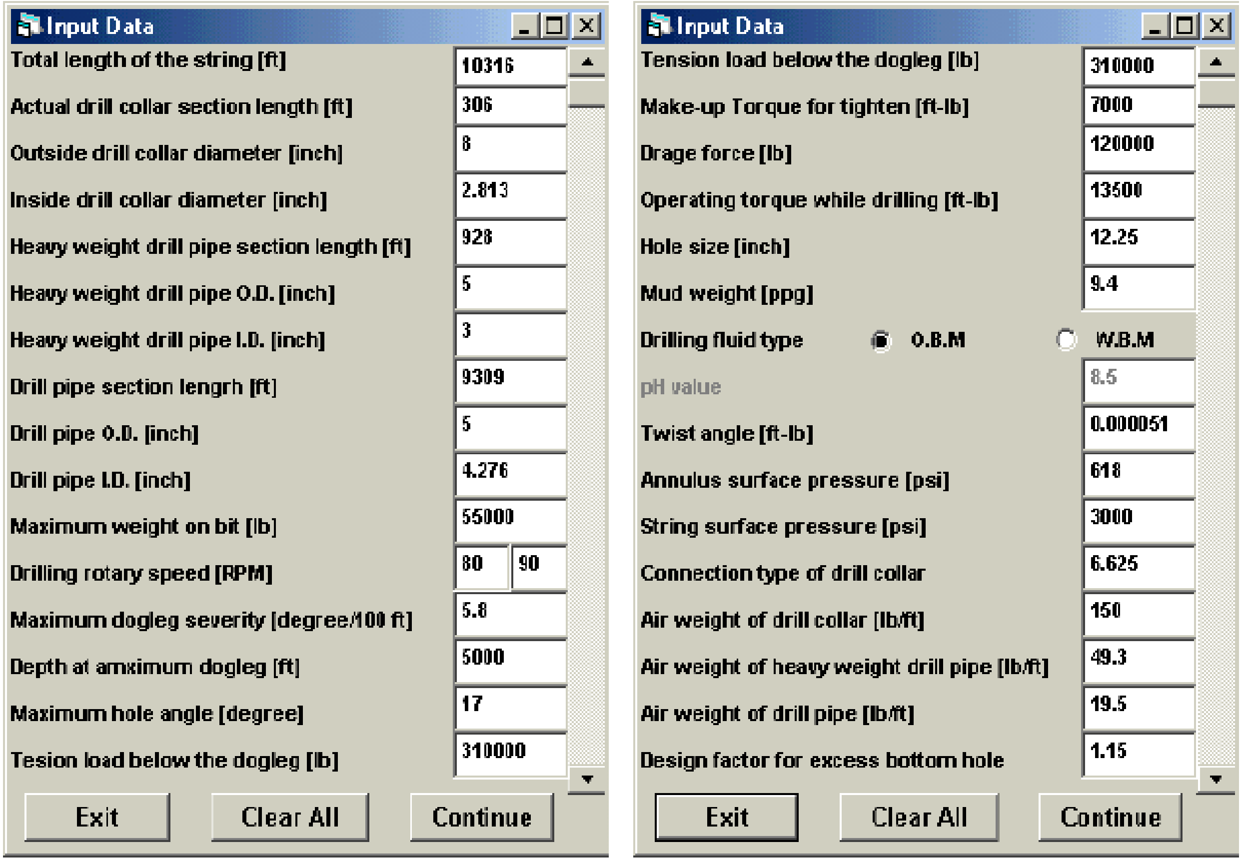

Fig. 2 Input data screen

3.3 Output Screen

Examples of the output screens are shown in Fig. 3a,b. The program will calculate the maximum permissible dogleg severity and compare it with the maximum dogleg while drilling. If the maximum dogleg severity is greater than the maximum permissible dogleg severity, the program will highlight the command of failure occur (as shown in Fig. 3a). Else, check the following item by click on the next button to get the results of the next item and so on. When you click on the next button the operating torque evaluation screen will appear, whereas the program will calculate the angle of twist according to the operating torque and compare it with the recommended angle of twist. If the calculated angle of twist is less than the recommended angle of twist the program will highlight the command of failure not occur (as shown in Fig. 3b).

(a) (b)

Fig. 3.a,b Examples of program output Screens, (a) Evaluating dogleg severity screen, and (b) Evaluating operating torque screen

4 Results and Discussion

4.1 Failure Case Studies

The following cases are actual failure cases occurred in Gulf of Suez Petroleum Company (GUPCO) in Gulf of Suez area and Western Desert area. The developed computer program is applied on these failure cases to test its validity. Table 2 summarizes the actual data for these cases. The orders of the resulted reasons caused drill string failure for the tested cases obtained from the designed programs are listed in Table 3.

Case #1

This development well drilled in the Western Desert Concession in the onshore Abul-Gharadig area in 1991. Egyptian drilling company Rig No.8 (EDC-8) was used to drill this well to a total depth (TD) of 10,616 ft. While drilling 12.25-inch hole from 10,503 ft to 10,616 (TD) through the Limestone of Abu Roash formation with rotary bottom hole assembly and water base mud, lost 350 psi. When pulling out of hole, washout in Shock Sub was detected.

Case #2

This development well drilled in the Gulf Of Suez Concession in the offshore Ramadan area in 1993. Pyramid drilling Rig (Bennevis) was used to drill this well to a total depth (TD) of 12,504 ft. While drilling 12.25-inch hole from 10,805 ft to 10,823 through the Shale and Limestone of Mheiherrat formation with rotary bottom hole assembly and water base mud, lost 300 psi. Pull out of hole, found vertical crack in the top joint of heavy weight drill pipe.

Case #3

This development well drilled in the Gulf Of Suez Concession in the offshore Hilal area in 1993. Sonat Offshore drilling Rig (Mercury) was used to drill this well to a total depth (TD) of 10,267 ft. While drilling 12.25-inch hole from 8,747 ft to 8,961 through the Limestone of Rudeis formation with rotary bottom hole assembly- and water base mud, lost 600 psi. Pull out of hole, found hole in the drill pipe near the surface.

Table 2 Summarizes the actual data for the tested cases.

Parameters	Units	Case1	Case2	Case3	Case4	Case5
Total length of the string	feet	10,616	10,823	8,961	10,239	12,480
Length of the drill pipe	feet	9,309	9,595	7,450	9,557	11,715
O.D of the drill Pipe	inch	5	5	5	5	5
I.D. of Drill Pipe	inch	4.276	4.276	4.276	4.276	4.276
Maximum WOB	lb	55,000	30,000	50,000	30,000	50,000
Drilling rotary speed	RPM	80/90	80/90	170/180	150/200	125/150
Maximum dogleg severity	Degree/ 100 ft	5.8	8.7	4.1	4.0	3.5
Length of drill collar section	feet	306	89	193	318	162
O.D of the drill collar	inch	8	8	8	8	8
I.D. of the drill collar	inch	2.813	2.813	2.813	2.813	2.813
HWDP Length	ft	928	1,083	1,225	0.0	544
HWDP O.D.	inch	5	5	5	----	5
HWDP I.D.	inch	3	3	3	----	3
Maximum hole angle	degree	17	25	7.82	58	51
Tension load below the dogleg	lb	310,000	90,000	50,000	30,000	20,000
Drag force	lb	120,000	90,000	50,000	30,000	20,000
Operating torque while drilling	Amps	400	650	400	500	760
Hole size	inch	12.25	12.25	12.25	12.25	12.25
Drilling fluid type	-----	WBM	WBM	WBM	OBM	WBM
Mud weight	ppg	9.4	13.6	10.6	12.5	10.6
pH value	-----	8.5	8.0	8.8	-----	9.0
Annulus surface pressure	psi	618	650	650	620	650
String surface pressure	psi	3000	3100	3200	3450	2600
Connection type of the drill collar	-----	6.625 inch Regular	6.625 inch Regular	6.625 inch Regular	6.625 inch Regular	6.625 inch Regular
Type of formation drilled	-----	Limestone	Shale and Limestone streaks	Limestone	Anhhy-drite	Salt and Limestone with sand streaks

Table 3 Program results for the tested cases.

Cases Reasons	Case #1	Case #21	Case #3	Case #4	Case #5
1	Dogleg severity	Dogleg severity	Operating torque	Operating torque	Operating torque
2	Critical RPM	Operating torque	Stiffness ratio	Absence of heavy weight drill pipe	Heavy weight drill pipe length
3	Stiffness ratio	Stiffness ratio	Hole size	Stiffness ratio	Stiffness ratio
4	Hole size	Hole size	Formation type	Hole size	Hole size
5	Formation type	PH value <10	PH value <10	Formation type	Formation type
6	PH value <10	---------	---------	---------	PH value <10

Case #4

This development well drilled in the Gulf Of Suez Concession in the offshore October area in 1995. Sonat Offshore drilling Rig (Comet) was used to drill this well to a total depth (TD) of 16,080 ft. While drilling 12.25-inch hole from 10,035 ft to 10,239 through the Anhydrite of South

Gharib formation with rotary bottom hole assembly and oil base mud, lost 300 psi. Pull out of hole, found the short drill collar cleaned smooth cut 0.3 ft from the boxfish neck area.

Case #5

This Exploratory well drilled in the Gulf Of Suez Concession in the offshore Badri area in 1995. Santa Fe International Rig No.124 was used to drill this well to a total depth (TD) of 12,480 ft. While drilling 12.25 inch hole from 12,417 ft to 12,480 through the Salt with Shale, Limestone and Sand Streaks of Ayun Musa formation with rotary bottom hole assembly and water base mud, had very hard back ream and very high torque, pump pressure dropped 1200 psi. Pull out of hole; found the drill string backed off at the short drill collar.

5 Conclusions and Recommendations

1- Higher cabapility of the designed program to detect and recognise the resones for drill string failure is obtained with less effort and short time, and this program will be a guide for any future case, as it will be used to characterize the reasons that may lead to that failure.

2- Drill string failure does not usually occur due to a unique reason or a unique factor. It depends on a lot of reasons and factors that could be accumulated and lead to the drill string failure. The best way to avoid drill string failure before and while drilling is to run the degined program to carefully diagnose and detect if the drill string is close to fail and hence an immediate action is taken to improve the drilling parameters to prevent the drill string failure.

3- The major factors that lead to drill string failure, for the tested cases are: dogleg severity, rotary bottom hole assembly, higher operating torque while drilling, had formation, and hole size specially 12.25-inch

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Corresponding Author: **shokir@ksu.edu.sa**