Chapter Three

Methodology

This chapter presents the steps and procedures that have been followed for the design and analysis for slim hole well by sidetracking from an abandonment well and utilizing some software tools (Landmark, abaqus FE software, and Matlab software program). Before explain design and analysis process it is necessary to briefly explain the landmark software, abaqus FE and matlab program (GUI).

3.1 Landmark Software:

This software is used to simulate drilling operation. It can either be used to plan/analyse the process of building a new site or to evaluate possible alternatives in actual problem. The user is required to input the data and the software has a range of modules to assess the data, this software developed by Halliburton. Land mark software mainly contains the following:

- Compass, it involves varies input data like survey to ensure well path on 3-D plot.
- Well Plan, involves varies input data about the well to analysis effective parameter like Bottom Hole Assembly Analysis.

3.1.1 Compass:

Compass is directional well planning software developed by Halliburton. It is used for path planning, survey data management, and anti-collision analysis. The software is deployed on Landmark's Engineer's Data Model (EDM) enabling data consistency and reduced planning cycle times by sharing common data compass has three core functions; planning to design the shape of proposed well paths, survey to calculate as drilled well path position, and anti-collision to calculate distance between well paths (Landmark compass user manual ,2003).

3.1.2 WellPlan:

Well plan for windows is a Drilling Engineering application environment designed for use by drilling engineer. Wellplan is a component of Landmark software developed by Halliburton. Wellplan software is able to solve number of technical challenges such as ERD, slim-hole drilling deep water drilling, and environmentally sensitive drilling areas. Wellplan software can be used at the rig site and in the office to provide integration between engineering functions. It is used during the design and operational phases for drilling and well completion. This software allows the user to identify potential problems during the drilling and completion process in terms of wellbore design. Integrated technologies enables the user to study and evaluate BHA, torque and drag, stuck pipe, cementing, hydraulics, well control, Notebook, and Surge.

3.2 Abaqus FE Software:

Is a software suite for finite element analysis (FEA) and computer-aided engineering (CAE), originally released in 1978. The name and logo of this software are based on the abaqus calculation tool.

Abaqus is used in the automotive, aerospace, and industrial products industries. The product is popular with academic and research institutions due to the wide material modelling capability, and the program's ability to be customized. Abaqus also provides a good collection of multiphysics capabilities, such as coupled acoustic-structural, piezoelectric, and structural-pore capabilities, making it attractive for production-level simulations where multiple fields need to be coupled.

Solution Sequence:

Every complete finite-element analysis consists of three separate stages:

- Pre-processing or modelling: This stage involves creating an input file, which contains an engineer's design for a finite-element analyzer also called solver.
- Processing or finite element analysis: This stage produces an output visual file.
- Post-processing or generating report, image, animation, etc. from the output file: This stage is a visual rendering stage.

3.3 Matlab Program (GUI):

The name matlab stands for MATrix LABoratory. matlab was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects.

Matlab is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, Matlab is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make Matlab an excellent tool for teaching and research.

A graphical user interface (GUI) is a graphical display that contains devices, or components, that enable a user to perform interactive tasks. To perform these tasks, the user of the GUI does not have to create a script or type commands at the command line. Often, the user does not have to know the details of the task at hand.

The GUI components can be menus, toolbars, push buttons, radio buttons, list boxes, and sliders-just to name a few. In Matlab, a GUI can also display data in tabular form or as plots, and can group related components.

The GUI contains:

- An axes component.
- A pop-up menu listing three data sets that correspond to Matlab functions: peaks, membrane, and sinc.
- A static text component to label the pop-up menu.
- Three buttons that provide different kinds of plots: surface, mesh, and contour When you click a push button, the axes component displays the selected data set using the specified plot.

3.4 Slim Hole Sidetrack Design and Analysis:

This part explain how to design and analysis slim hole well with hole size 6 inch from abandon well to hit new target closed to abandon well in hamra oil field, the design and analysis includes:

i. Well Trajectory.
ii. Window Milling.
iii. Bottom Hole Assembly (BHA).
iv. Hydraulic.
v. Wellbore stability.
vi. Torque and drag.

3.4.1 Well Trajectory:

The well trajectory design is considered the first step in the design, illustrating the well path. The process includes using Landmark Compass software package are:

- Data Required.
- Azimuth Calculation.
- Trajectory Calculation.
- Input data in compass.

3.4.1.1 Data Required:

The minimum Data required to design well trajectory is:

- Abandon well Co-ordinates: (Easting, Northing).
- Kick-off Point (KOP).
- Buildup Rate (BUR).
- Target Co-ordinates: (Easting, Northing).
- Target TVD.
- Total horizontal departure.

3.4.1.2 Azimuth Calculation:

$$Azimuth = \tan^{-1}\left(\frac{\Delta East}{\Delta North}\right) \quad (3.1)$$

3.4.1.3 Trajectory Calculation:

In this project have been selected build-up hold profile to design slim hole sidetrack trajectory. The equations of build-up hold design are:

- Build-up & hold type well; R < total target displacement:

1. Build Section:

- radius of curvature R_1:

$$R_1 = \frac{180 \times 30}{\pi \times BUR} \quad (3.2)$$

$R_2 = 0$

Where:

BUR =Buildup rate.

- The maximum inclination angle I_{max} is given by:

$$I_{max} = 2\tan^{-1}\left(\frac{D_4 - D_1 - \sqrt{X_4^2 + (D_4 - D_1)^2 - 2(R_1 + R_2)X_4}}{2(R_1 + R_2) - X_4}\right) \quad (3.3)$$

- Measure depth of build section:

$$\Delta L = \left(\frac{\pi}{180}\right) R_1 I_{deg} \quad (3.4)$$

- True vertical depth for build section:

$$\Delta y = R_1 \sin I \quad (3.5)$$

- Total horizontal departure of build section:

$$X_{build} = R_1 \times (1 - \cos(I_{max})) \quad (3.6)$$

2. Hold Section:

- Measure depth of hold section:

  From triangles calculation.

- True vertical depth for hold section:

  From triangles calculation.

- Total horizontal departure of hold section:

  From triangles calculation.

3. Measure Depth of Target:

$$MD = D_1 + \Delta L + L_{hold} \quad (3.7)$$

3.4.1.4 Input Data in Compass:

The need for Compass in this project is to generate the well trajectory or profile. Before inputting the survey data, to get the well geometry, there is some basic data need to be inputted such as: new company, new field, new site, new well, and new wellpath.

3.4.2 Window Milling:

Abaqus software used to simulate milling of casing and sidetrack from abandon well to hit a new target in hamra field. Input data in abaqus software to construct casing, milling bit, and whipstock model by the follow steps:

- Input Data.
- Model Parts construction.

- Assignment of model's mechanical properties.
- Sidetrack Assembly.
- Model contact Interaction.
- Model boundary condition.
- Model parts Mesh.
- Running abaqus FE.
- Result output and Visualization.

3.4.2.1 Input Data:

In this process the required data of material properties includes:

- Mass density.
- Young's Modulus.
- Poisson's Ratio.
- Yield Stress.
- Plastic Strain.

3.4.2.2 Model Parts Construction:

In this step, all geometrical shapes established includes:

- Milling Bit.
- Casing.
- Whipstock.

3.4.2.3 Assignment of Model's Mechanical Properties:

In this step, in put properties for each geometrical shape individual to obtain the required specification for milling bit, casing, and whipstock. Each shape of this has specific kind of data related to mechanic material includes density, elastic, plastic.

After input all properties in to geometrical shapes, the color of geometrical shapes will change to another (green), color to explain the shapes became has the properties except rigid shape (whipstock) still the same color.

3.4.2.4 Sidetrack Assembly:

Aggregation geometric shape with each other to obtain required model. milling bit, casing, and whipstock inside the hole and this is similar the real situation.

3.4.2.5 Model Contact Interaction:

When we deal with multi-parts analysis, interaction between parts' surfaces can greatly affect the simulation results, that will have made definition between all surfaces of parts/and nodes.

3.4.2.6 Model Boundary Condition:

Determine the boundary condition (BC) for each part individually. Casing and whipstock have fixed at all direction but milling bit free at all direction and rotate at z axis's to allow a bit for milling casing and make sidetrack.

After input boundary condition (BC) data for all parts, the parts will be having point on it edge.

3.4.2.7 Model Parts Mesh:

Discretized all parts into smaller elements to obtain accurate analysis for every small region on the parts and then will get accurate result.

3.4.2.8 Running Abaqus FE:

In this step the execution of the model and also monitoring the process to detect any mistakes in the model.

3.4.2.9 Result Output and Visualization:

In this step, the result displayed in visual mode to determine and apparent deformable and undeformable regions in the model. Also the results on tables or plots are available.

3.4.3 Bottom Hole Assembly (BHA):

BHA Design is considered the most important design; the design process includes:

- Selection BHA.
- Drill Collar and HWDP Calculation.

- Input data in landmark.

3.4.3.1 Selection BHA:

In this step selected internal and external diameters for drillcollar, HWDP, jar, Non-Mag Drill collar, MWD, Sub, mud motor, and bit. By using standard Tables.**3.1**, **3.2**, **3.3**, **3.4**, **3.5** and **3.6** show it below:

Table (3.1): Drill Collars and Hole Sizes (Rabia H).

Hole Section	Recommended Drill Collar OD (ins)
36	9½ + 8
26	9½ + 8
17½	9½ + 8
16	9½ + 8
12¼	8
8½	6¼
6	4¾

Table (3.2): Standard Sizes, Bores and Connections for Drill Collars (RDT,2010).

Collar Number[1] or Size and Type	Minimum Drill Collar OD	Bore Tolerance +1/16"-0"	Length (ft.) Tolerance +/- 6	Bending Strength Ratio[2]
NC 23-31	3-1/8	1-1/4	30	2.57:1
NC 26-35 (2-3/8 IF)	3-1/2	1-1/2	30	2.42:1
NC 31-41 (2-7/8 IF)	4-1/8	2	30	2.43:1
NC 38-47	4-3/4	2-1/4	31	1.85:1
NC 38-50 (3-1/2 IF)	5	2-1/4	31	2.38:1
NC 44-60	6	2-1/4	31	2.49:1
NC 44-60	6	2-13/16	31	2.84:1
NC 44-62	6-1/4	2-1/4	31	2.91:1
NC 46-62 (4 IF)	6-1/4	2-13/16	31	2.63:1
NC 46-65 (4 IF)	6-1/2	2-1/4	31	2.76:1
NC 46-65 (4 IF)	6-1/2	2-13/16	31	3.05:1
NC 50 (4 IF)	6-3/4	2-1/4	31	3.18:1
NC 50-70 (4-1/2 IF)	7	2-1/4	31	2.54:1
NC 50-70 (4-1/2 IF)	7	2-13/16	31	2.73:1
NC 50-72 (4-1/2 IF)	7-1/4	2-13/16	31	3.12:1
NC 56-77	7-3/4	2-13/16	31	2.70:1
6-5/8 Reg	8	2-13/16	31	2.60:1
6-5/8 Reg	8-1/4	2-13/16	31	2.93:1
NC 61-90	9	2-13/16	31	3.17:1
7-5/8 Reg	9-1/2	3	31	2.81:1
7-5/8 Reg[3]	9-3/4	3	31	3.09:1
NC 70-100	10	3	31	2.81:1
8-5/8 Reg[3]	11	3	31	2.85:1

Table (3.3): Dimensional Data Range of Heavy Weight Drill Pipe (Directional Drilling Training Manual,1996).

	TUBE							TOOL JOINT					WEIGHT		
	Nom. Tube Dimension					Mechanical Properties Tube Section					Mechanical Properties Tube Section		Approximate Weight Including Tube & Joints (lb)		
Nom. Size (A)	ID (B)	Wall Thick-ness	Area (in²)	Center Upset (C)	Eleva-tor Upset (D)	Tensile Yield (lb)	Tor-sional Yield (ft-lb)	Connector Size & Type	OD (E)	ID	Tensile Yield (lb)	Tor-sional Yield (ft-lb)	Wt./ft	Wt./Jt. 30 ft	Make-up Torque (ft-lb)
3 1/2	2 1/16	.719	6.280	4	3 5/8	345,400	19,575	N/C. 38(3 1/2 I.F.)	4 3/4	2 3/16	345,400	19,575	25.3	760	9,900
4	2 9/16	.719	7.410	4 1/2	4 1/8	407,550	27,635	N.C. 40(4 I.F.)	5 1/4	2 11/16	407,550	27,635	29.7	890	13,250
4 1/2	2 3/4	.875	9.965	5	4 5/8	548,075	40,715	N.C. 46(4 I.F.)	6 1/4	2 7/8	548,075	40,715	41.0	1230	21,800
5	3	1.000	12.556	5 1/2	5 1/8	691,185	56,495	N.C. 50(4 1/2 I.F.)	6 1/2	3 1/8	691,185	56,495	49.3	1480	29,400

Table (3.4): Specification of Hydraulic Jars (Schlumberger,2012).

OD, in	ID, in	Tool joint connection, in	Overall length extended, ft	Maximum detent working load, lbf	Tensile yield strength, lbf	Torsional yield strength, lbf.ft	Up stroke, in	Down stroke, in	Total stroke, in	Tool weight, lbm
3⅜	1½	2⅜ API IF	24.42	44,000	236,062	6,842	7	7	21	500
4¼	2	2⅞ API IF	29.83	70,000	377,871	15,381	8	7	25	800
4¾	2¼	3½ API IF	29.83	95,000	492,284	19,126	8	7	25	1,050
5⅛	2¼	WT-38	29.83	95,000	492,284	30,000	8	6 13/16	25	1,155
6¼	2¾	4½ XH	31.17	150,000	730,324	40,505	8	7	25	1,600
6¼ Mod	2¾	4½ XH	31.17	150,000	964,207	50,757	8	7	25	1,600
6½	2¾	4½ API IF	31.17	175,000	964,207	54,796	8	7	25	1,850
7	2¾	5 H-90	31.50	230,000	1,179,933	67,396	8	8	25	2,600
7¼	2¾	5½ H-90	31.50	240,000	1,261,162	84,155	8	8	25	3,000
7¾	3	6⅝ API REG	32.00	260,000	1,315,225	86,848	8	7	25	3,200
8	3	6⅝ API REG	32.00	300,000	1,621,565	98,490	8	7	25	3,550
8¼	3	6⅝ API REG	32.00	350,000	1,819,384	115,418	8	8	25	4,000
8½	3	6⅝ API REG	32.00	350,000	1,846,269	115,418	8	8	25	4,500
9½	3	7⅝ API REG	32.50	500,000	1,654,172	152,802	8	8	25	5,600

Table (3.5): Standard Sizes, Weight and Length for NMDC (SB Darron).

DIMENSION	WEIGHT KG/PC	WEIGHT LBS/PC	LENGTH FEET	PPF	KG/M
3 1/2" x 2"	317	699	31	22.5	33.5
3 3/4" x 2"	384	847	31	27.3	40.6
4" x 2 1/4"	418	922	31	29.7	44.2
4 1/8" x 2 1/4"	460	1014	31	32.7	48.7
4 1/4" x 2 1/4"	497	1096	31	35.3	52.6
4 3/4" x 2 1/4"	658	1451	31	46.8	69.6
4 3/4" x 2 11/16"	588	1296	31	41.8	62.2
4 3/4" x 2 13/16"	560	1235	31	39.8	59.3
5" x 2 13/16"	652	1437	31	46.4	69.0
5 1/4" x 2 13/16"	750	1653	31	53.3	79.4
5 1/2" x 2 13/16"	853	1881	31	60.7	90.3
6 1/4" x 2 13/16"	1210	2668	31	86.1	128.1
6 1/2" x 2 1/4"	1450	3197	31	103.1	153.5
6 1/2" x 2 13/16"	1325	2921	31	94.2	140.2
6 1/2" x 2 13/16"	1250	2756	31	88.9	132.3
6 1/2" x 3 1/4"	1191	2626	31	84.7	126.0
6 3/4" x 2 13/16"	1460	3219	31	103.8	154.5
6 3/4" x 3"	1374	3029	31	97.7	145.4
6 3/4" x 3 1/4"	1315	2899	31	93.5	139.2

Table (3.6): API Casing Dimensions and Bit Diameter.

Dimensions					Bit Size	
Casing OD	Wall Thickness [in]	Casing ID [in]	Casing Coupling OD [in]	API Drift Diameter [in]	Recommended Bit Diameter [in]	[mm]
4 ½"	0.205	4.090	5.000	3.965	3 7/8	98.4
	0.224	4.052		3.927		
	0.250	4.000		3.875		
	0.290	3.920		3.795	3 ¾	95.2
5"	0.220	4.560	5.563	4.435	4 ¼	107.9
	0.253	4.494		4.369		
	0.296	4.408		4.283		
	0.362	4.276		4.151	4 1/8	104.8
5 ½"	0.244	5.012	6.050	4.887	4 7/8	123.8
	0.275	4.950		4.825	4 ¾	120.7
	0.304	4.892		4.767		
	0.361	4.778		4.653	4 5/8	117.5
	0.415	4.670		4.545	4 ½	114.3
6 5/8"	0.288	6.049	7.390	5.924	5 7/8	149.2
	0.352	5.921		5.796	5 ¾	146.1
	0.417	5.791		5.666	5 5/8	142.8
	0.475	5.675		5.550	5 ¼	133.4
7"	0.231	6.538	7.656	6.413	6 ¼	158.7
	0.272	6.456		6.331		
	0.317	6.366		6.241		
	0.362	6.276		6.151	6 1/8	155.5
	0.408	6.184		6.059	6	152.4
	0.453	6.094		5.969	5 7/8	149.2
	0.498	6.004		5.879		
	0.540	5.920		5.795	5 ¾	146.1

3.4.3.2 Drill Collar and HWDP Calculation:

- Minimum data Required:
  - Hole Size.
  - Well Inclination.
  - Mud Density.
  - Required WOB.
  - Drill collar OD/ID.
  - HWDP OD/ID.
  - Nominal weight for Dc and HWDP.
- Calculation:

1- Determine the buoyancy factor for the mud weight in use using the formula below:

$$BF = 1 - \frac{MW}{65.5} \quad (3.8)$$

Where:

BF = Buoyancy Factor, dimensionless.

MW = Mud weight in use, ppg.

65.5 = Weight of a gallon of steel, ppg.

2- Calculate the required collar number to achieve the desired weight on bit:

$$DC_{length} = \frac{WOB}{BF \cos I} \quad (3.9)$$

where:

WOB = Desired weight on bit, lbf (x 1000).

I = well inclination.

3- Calculate the required collar and HWDP length to achieve the desired weight on bit.

3.4.3.3 Input Data in Landmark:

BHA data and calculation data entered in landmark software to make simulator and analysis by using BHA modelling. This process includes:

- Input required data for the analysis.

- Create analysis plots:(Side force, Displacement).
- Interpret analysis plots to analyze string behavior over a range of operating parameters.

3.4.4 Hydraulic:

This project designed and analysis for surge/swab and analysis for hole cleaning in hydraulic model.

3.4.4.1 Surge and Swab:

- **Data Required:**
  - Value at 600 viscometer dial reading.
  - Value at 300 viscometer dial reading.
  - Hole diameter.
  - Drill pipe diameter.
  - Inner diameter of drill pipe.
  - Length of drill pipe.
  - Pipe movement velocity.
  - Drill collar diameter.
  - Length of drill collar.
- **Calculation:**

The calculation steps are as follows:

1. Determine pressure around drill pipe:

i. Determine, n

$$n = 3.32 \log\left(\frac{\theta_{600}}{\theta_{300}}\right) \quad (3.10)$$

Where:

n = is the power law exponent.

θ_{600} = is a value at 600 viscometer dial reading.

θ_{300} = is a value at 300 viscometer dial reading.

ii. Determine, k

$$K = \frac{\theta_{300}}{(511)^n}\text{...(3.11)}$$

Where:

K = is the fluid consistency unite.

iii. Determine fluid velocity around drill pipe, V_{dp}

- For closed ended pipe (plugged flow):

$$V_{dp} = \left(0.45 + \frac{D_p^{\,2}}{D_h^{\,2} - D_p^{\,2}}\right) \times Vp\text{..(3.12)}$$

Where:

V_{dp} = is the fluid velocity around drill pipe in ft/min.

V_p = is pipe movement velocity in ft/min.

D_p = is drill pipe diameter in inch.

D_h = is hole diameter in inch.

iv. Maximum pipe velocity, V_m

Vm =Vdp x 1.5…………………………………………………..........… (3.13)

Where:

V_m = is maximum pipe velocity.

v. Pressure loss around drill pipe, P_{dp}

$$p_{dp} = \left(\frac{2.4 \times V_m}{D_h - D_p} \times \frac{2n+1}{3n}\right)^n \times \frac{KL}{300(D_h - D_p)}\text{.....................................(3.14)}$$

Where:

L = is length of drill pipe.

2. Determine pressure loss around drill collar:

1. Determine fluid velocity around drill collar, V_{dc}

-for close ended pipe (plugged flow):

$$V_{dc} = \left(0.45 + \frac{D_c^{\,2}}{D_h^{\,2} - D_c^{\,2}}\right) \times V_{pc}\text{ ……………...………………..... (3.15)}$$

Where:

V_{dc} = is the fluid velocity around drill collar in ft/min.

D_c = is drill collar diameter in inch.

2. Maximum pipe velocity, V_m

$$V_m = V_{dc} \times 1.5 \text{ .... } (3.16)$$

3. Pressure loss around drill collar, P_{dc}

$$p_{dc} = \left(\frac{2.4 \times V_m}{D_h - D_c} \times \frac{2n+1}{3n} \right)^n \times \frac{KL}{300(D_h - D_c)} \text{ .... } (3.17)$$

Where:

L = is length of drill collar.

3. Determine total pressure loss:

Total pressure loss = $P_{dp} + P_{dc}$ ……………………...…………………… (3.18)

4. Determine surge and swab pressure:

$$P_{hydrulic} = 0.052 \times \rho \times h \text{ .... } (3.19)$$

Where:

ρ = Mud density (ppg).

h = Total vertical depth (ft).

-For surge pressure:

Bottom hole pressure =hydrostatic pressure +total pressure loss……. (3.20)

$$Surge = \frac{P_{hydrulic} + P_{total}}{0.052 \times h} \text{ .... } (3.21)$$

-For swab pressure:

Bottom hole pressure =hydrostatic pressure –total pressure loss……. (3.22)

$$Swab = \frac{P_{hydrulic} - P_{total}}{0.052 \times h} \text{ .... } (3.23)$$

- **Input Data in Landmark:**

  Input data and calculation data of surge/swab in landmark software to make analysis by using surge/swab modelling.

3.4.4.2 Hole Cleaning Analysis:

- **Data Required:**
  - Flow rate: selected from the Table**.3.7** in below:

Table (3.7): National Oilwell Varco Pump Performance Data.

Liner size, inches (mm)			7 ¼" (184.2)	7" (177.8)	6 ¾" (171.5)	6 ½" (165.1)	6 ¼" (158.8)	6" (152.4)	5 ¾" (146.1)	5 ½" (139.7)	5" (127)	4 ½" (114.3)
Max. Discharge Pressure, psi (kg/cm^2) with high pressure Fluid End†			3200 (225)	3430 (241.1)	3690 (259.4)	3980 (279.8)	4305 (302.7)	4670 (328.3)	5085 (357.5)	5555 (390.5)	6720 (472.4)	7500 (527.2)
Pump Speed spm	Input HP, HP (kW)	Hyd.** HP, HP (kW)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)	GPM** (LPM**)
120*	1600* (1193*)	1440 (1074)	***	***	669 (2533)	621 (2349)	574 (2172)	529 (2002)	486 (1840)	444 (1682)	367 (1389)	297 (1124)
100	1333 (994)	1200 (895)	643 (2435)	600 (2270)	558 (2111)	517 (1958)	478 (1810)	441 (1668)	405 (1533)	370 (1401)	306 (1158)	248 (938)
80	1067 (796)	960 (716)	515 (1948)	480 (1816)	446 (1689)	414 (1566)	383 (1448)	353 (1334)	324 (1226)	296 (1121)	245 (927)	198 (750)
60	800 (597)	720 (537)	388 (1461)	360 (1362)	335 (1267)	310 (1175)	287 (1086)	264 (1001)	243 (920)	222 (841)	184 (697)	149 (564)
40	533 (397)	480 (358)	257 (974)	240 (908)	223 (844)	207 (783)	191 (724)	176 (667)	162 (613.1)	148 (561)	122 (462)	99 (375)
Volume/Stroke, gal. (Liters)			6.433 (24.35)	5.997 (22.70)	5.576 (21.11)	5.171 (19.58)	4.781 (18.10)	4.406 (16.68)	4.046 (15.32)	3.702 (14.02)	3.060 (11.58)	2.478 (9.38)

- Rotary speed (RPM).
- Rate of penetration (ROP).

- **Input Data in Landmark:**

  Input data in landmark to analysis cutting transport by using cutting transport modelling.

3.4.5 Wellbore Stability:

Using matlab program (GUI) for design a wellbore stability GUI program, it is contains two model, first model is Fracturing Gradient and second model is Mohr-Coulomb Collapse Gradient. The calculation for each model that have been used in program and data required to run program presents below:

3.4.5.1 Fracturing Gradient Model:

1- Normal stress, σ_X

$$\sigma_x = (\sigma_H \cos^2 \beta + \sigma_h \sin^2 \beta)\cos^2 \alpha + \sigma_V \sin^2 \alpha \qquad (3.24)$$

Where:

σ_H = Maximum horizontal stress.

σ_h = Minimum horizontal stress.

β = Azimuth from the σ_H-direction.

σ_V = Vertical insitu stress.

α = Inclination angle.

2- Normal stress, σ_y

$$\sigma_y = (\sigma_H \sin^2\beta + \sigma_h \cos^2\beta) \quad (3.25)$$

3- Normal stress, σ_z

$$\sigma_z = (\sigma_H \cos^2\beta + \sigma_h \sin^2\beta)\sin^2\alpha + \sigma_V \cos^2\alpha \quad (3.26)$$

4- Shear stress, σ_{xy}

$$\tau_{xy} = \tau_{yx} = -0.5(\sigma_H - \sigma_h)\sin 2\beta \cos\alpha \quad (3.27)$$

5- Shear stress, σ_{yz}

$$\tau_{yz} = \tau_{zy} = 0.5(\sigma_H - \sigma_h)\sin 2\beta \sin\alpha \quad (3.28)$$

6- Shear stress, σ_{zx}

$$\tau_{xz} = \tau_{zx} = -0.5(\sigma_H \cos^2\beta + \sigma_h \sin^2\beta - \sigma_V)\sin 2\alpha \quad (3.29)$$

7- Borehole pressure, p_w

$$p_w = 0.052(MW)D \quad (3.30)$$

Where:

D = True vertical depth.

MW = Mud weight.

8- Radial stress, σ_r

$$\sigma_r = p_w \quad (3.31)$$

9- Loop stress, σ_θ

$$\sigma_\theta = (\sigma_x + \sigma_y - p_w) - 2(\sigma_x - \sigma_y)\cos 2\theta - 4\tau_{xy}\sin 2\theta \quad (3.32)$$

Where:

θ = Loop angle.

10- Axial stress, σ_a

$$\sigma_a = \sigma_z - 2\nu(\sigma_x - \sigma_y)\cos 2\theta - 4\nu\tau_{xy}\sin 2\theta \quad (3.33)$$

Where:

ν = Poisson's ratio.

11- Shear stress, $\sigma_{a\theta}$

$$\tau_{a\theta} = \tau_{\theta a} = 2(\tau_{yz}\cos\theta - \tau_{xz}\sin\theta) \quad (3.34)$$

12- Shear stress, σ_{ar}

$$\tau_{ra} = \tau_{ar} = 0 \quad (3.35)$$

13- Shear stress, $\sigma_{r\theta}$

$$\tau_{r\theta} = \tau_{\theta r} = 0 \quad (3.36)$$

14- Fracturing Pressure

$$p_{frac} = \frac{\sigma_\theta + \sigma_a}{2} - \sqrt{\left(\frac{\sigma_\theta - \sigma_a}{2}\right)^2 + \sigma_{\theta a}^2} + |Y_{tens}| \quad (3.37)$$

Where:

$Y_{tens} = S_o$ = Cohesive strength.

3.4.5.2 Mohr-Coulomb Collapse Gradient Model:

15- Principal stress, σ_1

$$\sigma_1 = \frac{\sigma_\theta + \sigma_a}{2} + \sqrt{\left(\frac{\sigma_\theta - \sigma_a}{2}\right)^2 + \sigma_{a\theta}^2} \quad (3.38)$$

16- Principal stress, σ_2

$$\sigma_2 = \frac{\sigma_\theta + \sigma_a}{2} - \sqrt{\left(\frac{\sigma_\theta - \sigma_a}{2}\right)^2 + \sigma_{a\theta}^2} \quad (3.39)$$

17- Principal stress, σ_3

$$\sigma_3 = \sigma_r \quad (3.40)$$

18- Maximum principal stress, σ_{max}

$$\sigma_{\max} = \max(\sigma_1, \sigma_2, \sigma_3) \qquad (3.41)$$

19- Minimum principal stress, σ_{min}

$$\sigma_{\min} = \min x(\sigma_1, \sigma_2, \sigma_3) \qquad (3.42)$$

20- Maximum effective stress, σ'_{max}

$$\sigma'_{\max} = \sigma_{\max} - \alpha_p p_f \qquad (3.43)$$

Where:

α_p = Poroelastic constant.

p_f = Pore pressure.

21- Minimum effective stress, σ'_{min}

$$\sigma'_{\min} = \sigma_{\min} - \alpha_p p_f \qquad (3.44)$$

22- Mohr-Coulomb failure stress, σ_F

$$\sigma_F = 2S_o \tan\left(\frac{\pi + 2\phi}{4}\right) + \sigma'_{\min} \tan^2\left(\frac{\pi + 2\phi}{4}\right) \qquad (3.45)$$

Where:

ϕ = Friction angle

3.4.5.3 Minimum Data Required:

- Insitu Stresses:

  -True vertical depth, D

  -Pore pressure, p_f

  -Vertical insitu stress, σ_V

  -Maximum horizontal stress, σ_H

  -Minimum horizontal stress, σ_h

- Rock Properties:

  -Cohesive strength, S_o

  -Friction angle, ϕ

  -Poisson's ratio, ν

-Poroelastic constant, α_p

- Drilling Data:

-Inclination angle, α

-Azimuth from the σ_H-direction, β

-Loop angle, θ

-Mud weight, MW

3.4.6 Torque and Drag Analysis:

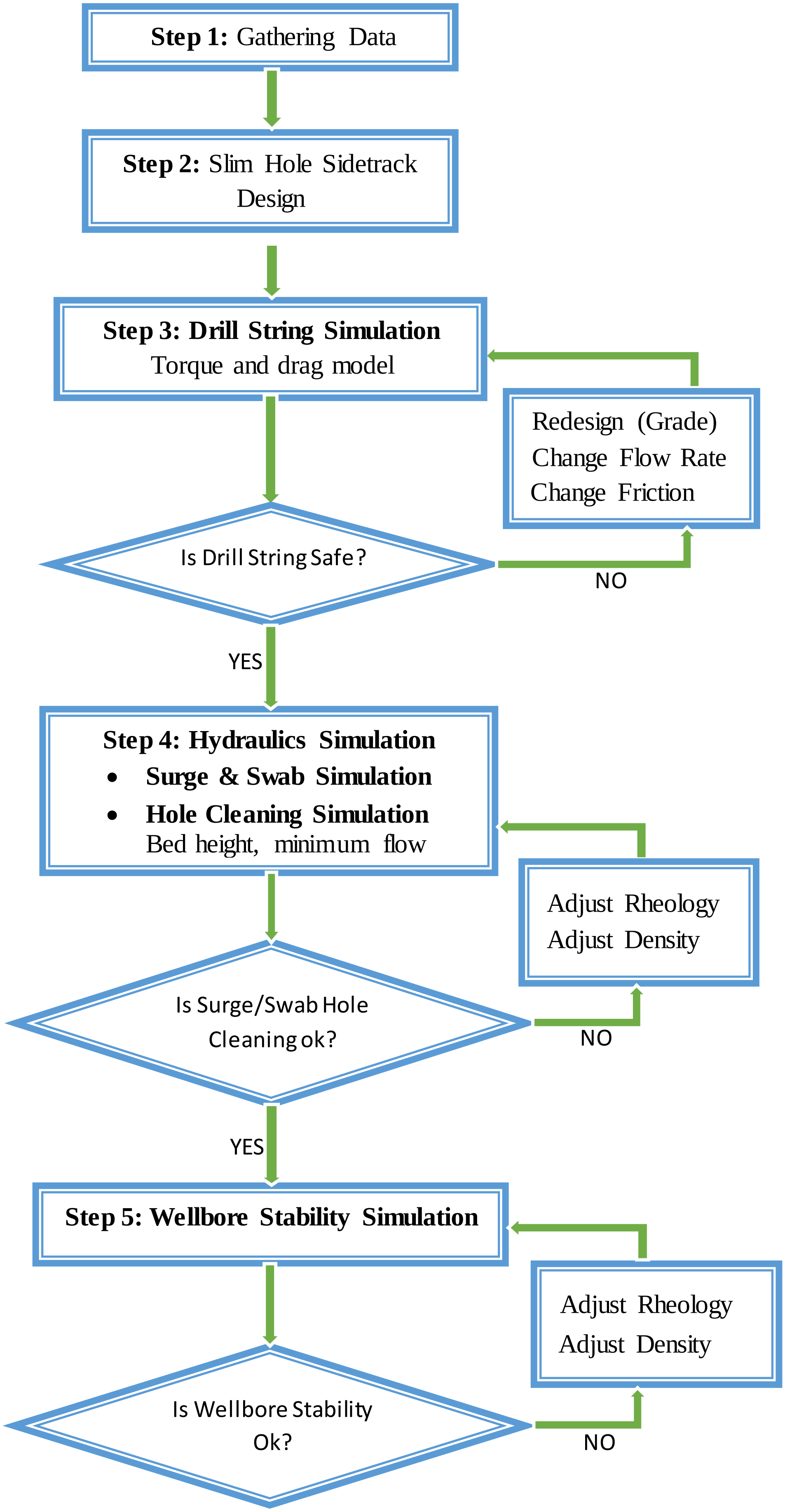
1- The analysis process involves reviewing of the available well and field data to understand and collect the data needed for the modelling process such as:

- Field and wells surface and subsurface data. In addition to the target location data.
- BHA and drillstring data for the well.
- Well trajectory
- Mud properties
- Actual field T&D data

2- Loading all the available data into the landmark software to analysis torque and drag by using normal torque model to explain if any buckling found in drilling string or other mechanical fatigue and simulate T&D.

3.5 Slim Hole Sidetrack Design and Analysis Flow Chart:

This part present the methodology used to design and analyse slim hole. Several trial and error simulation were carried out in order to select the right drill string grade and operational parameters, such as ROP, RPM, trip in and out speed, flow rate. Fig**.3.1** illustrates the design and analysis flow chart.



Step 1: Gathering Data
Step 2: Slim Hole Sidetrack Design
Step 3: Drill String Simulation
Torque and drag model
Redesign (Grade)
Change Flow Rate
Change Friction
Is Drill String Safe?
NO
YES
Step 4: Hydraulics Simulation
Surge & Swab Simulation
Hole Cleaning Simulation
Bed height, minimum flow
Adjust Rheology
Adjust Density
Is Surge/Swab Hole Cleaning ok?
NO
YES
Step 5: Wellbore Stability Simulation
Adjust Rheology
Adjust Density
Is Wellbore Stability Ok?
NO

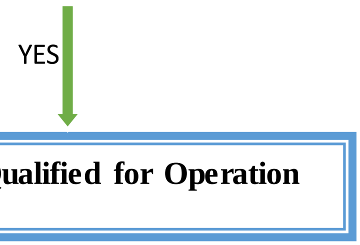


Fig (3.1): Design and Analysis Flow Chart