

Drilling Simulation Handout # 5 and 6

**PDC and Natural Diamond Bit (NDB)
ROP Models and Sensitivities
Study Using the “Optimizer”**

Handout#5&6 Outline:

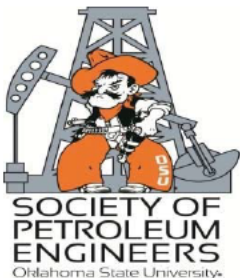
- General information about PDC and NDB (Natural Diamond Bits) drill bits and designs
- General information about PDC and NDB bit modeling and parameters effecting ROP.
- PDC and NDB parametric ROP sensitivity study using the “Optimizer”.

Drag Bits

Polycrystalline Diamond Compact (PDC)



Natural Diamond Bit (NDB)



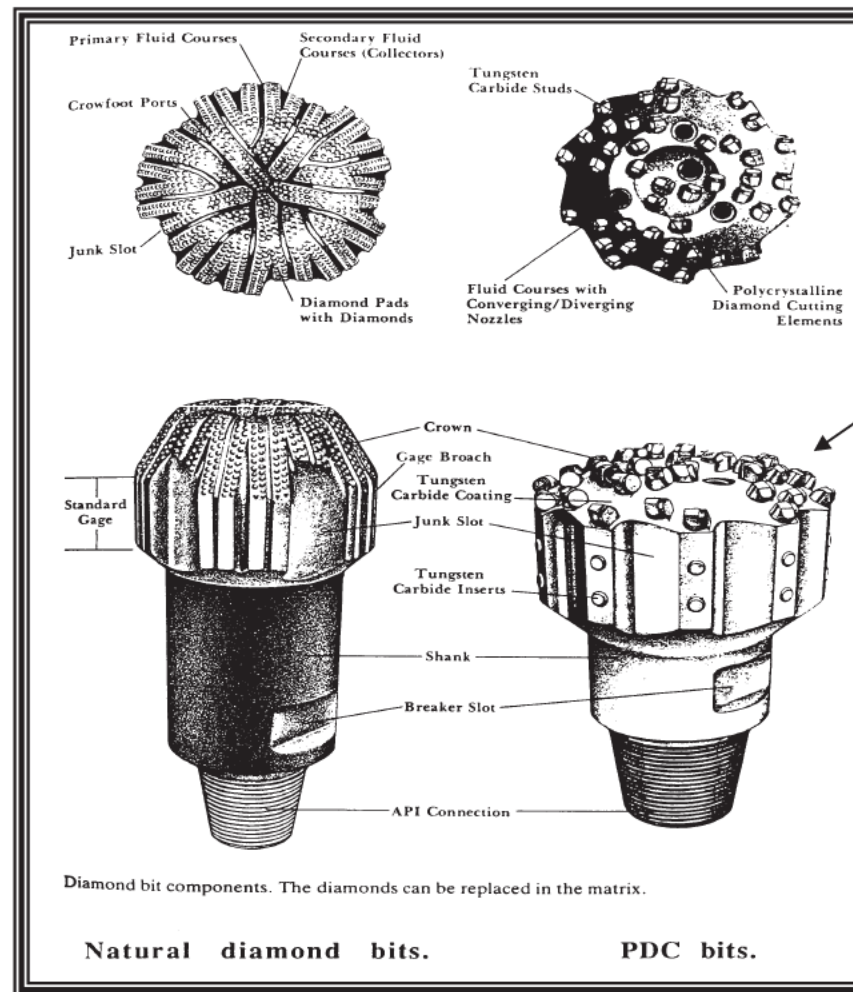
PDC and NDB - Fixed Cutter or Drag Bits

Advantages

- No rolling parts which require strong clean bearing surfaces
- Because it is made from one solid piece of steel there is less chance of bit breakage, which would leave junk in the bottom of the hole

Advantage of fixed cutter bits?

Fixed Cutter or Drag Bits (ND and PDC Bits)

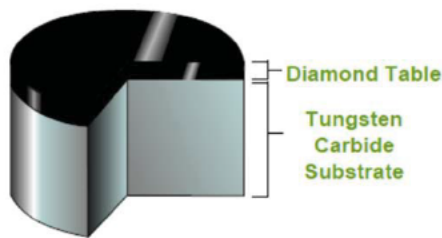


Old Matrix Design

Handout#5

Fixed Cutter PDC Bits

- Since mid 1970's a Polycrystalline Diamond Compact (PDC) Bits has been made possible by the introduction of a sintered polycrystalline diamond drill blanks, as a bit cutter element
- The drill blanks consist of a layer of a synthetic polycrystalline diamond that is bonded to a tungsten carbide substrate in a high-pressure high-temperature (HPHT) process



Conventional PDC Cutter

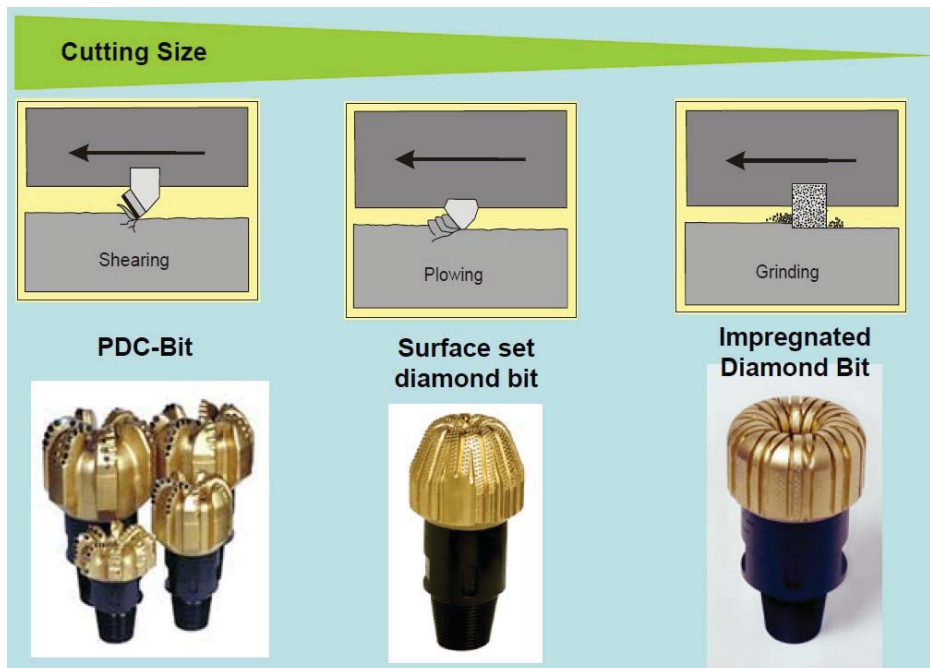


Newer Blade Design

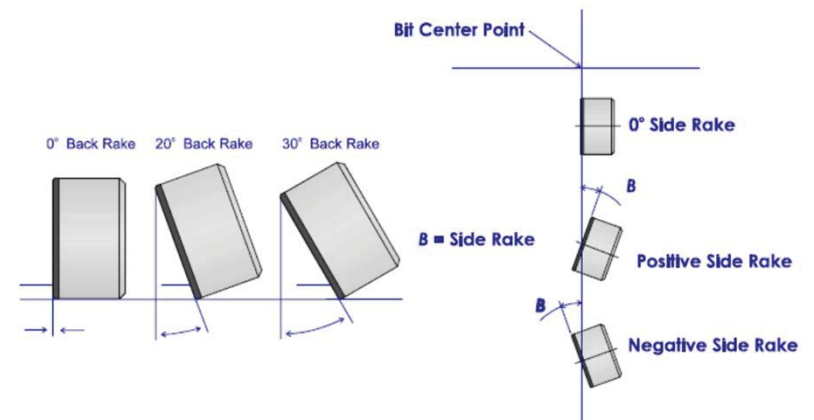
What does PDC stand for?

Cutting Action of PDC Bits

Drilling is achieved by physically plowing cuttings from the bottom of the bore-hole



Backrake & Siderake



What cutting action does an impregnated diamond bit have?

PDC Model

History

- The PDC ROP models developed by Glowka et al. at Sandia National Laboratories were based on the rock bit interaction force modeling of single PDC cutter data generated three lithologies. The model was integrated as a 3-D interaction between rock and cutters and predicted WOB for a given ROP in different lithologies.
- Sinor et al. continued the work and verified with laboratory data generalizing rock strength.
- The Optimizer PDC drill ahead model concept was patented in the late 1980's and later released.
- Pason Technology has this integrated into today's version of the "Optimizer".



Kinematics of PDC Bits

The coordinates of any point on a PDC bit can be represented by r , θ and h .

$$X_1 = r_c (\cos \alpha \cos \varphi \sin \gamma + \sin \alpha \cos \beta \cos \gamma - \cos \alpha \sin \varphi \sin \beta \cos \gamma) - h_c (\sin \varphi \sin \gamma + \cos \varphi \sin \beta \cos \gamma)$$

$$Y_1 = -r_c (\sin \alpha \sin \beta + \cos \alpha \sin \varphi \cos \beta) - h_c \cos \varphi \cos \beta$$

$$Z_1 = r_c (\cos \alpha \cos \varphi \cos \gamma + \cos \alpha \sin \varphi \sin \beta \sin \gamma - \sin \alpha \cos \beta \sin \gamma) - h_c (\sin \varphi \cos \gamma - \cos \varphi \sin \beta \sin \gamma)$$

$$r_1 = \sqrt{(R_c + x_1)^2 + y_1^2}$$

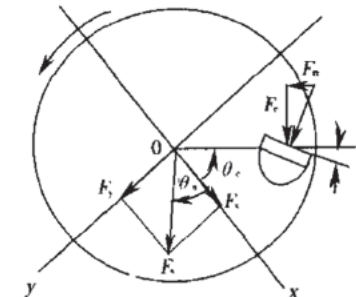
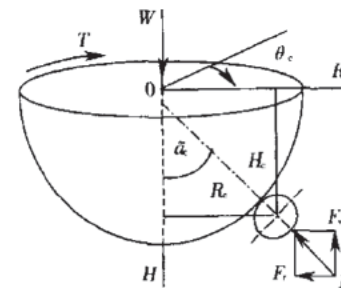
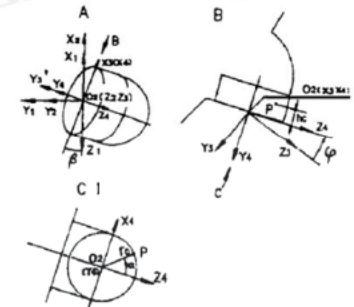
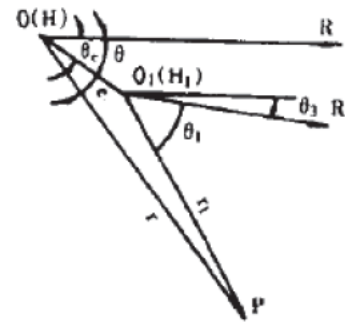
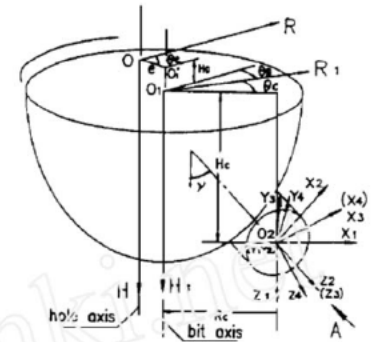
$$\theta_1 = \theta_c + \arctg(y_1 / (R_c + x_1))$$

$$h_1 = H_c + z_1$$

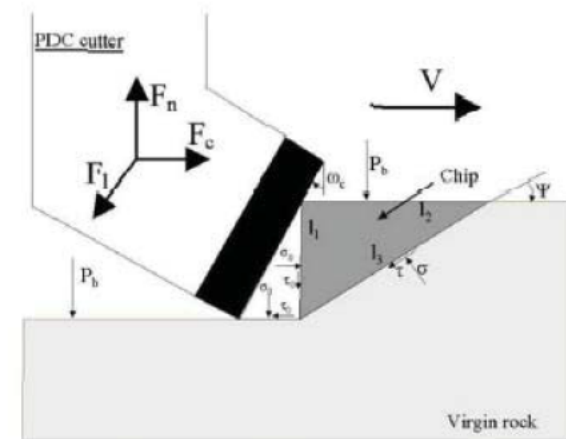
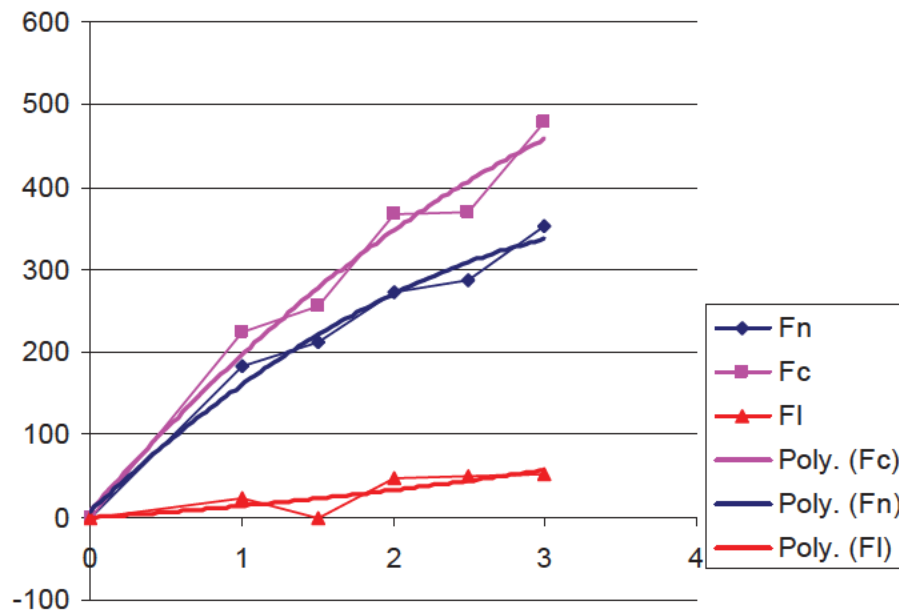
$$r = \sqrt{e^2 + r_1^2 + 2er_1 \cos(\theta_B + \theta_1 + \theta_e)}$$

$$\theta = \theta_e + \arctg[r_1 \sin(\theta_B + \theta_1 + \theta_e) / [e + r_1 \cos(\theta_B + \theta_1 + \theta_e)]]$$

$$h = H_0 + h_1$$



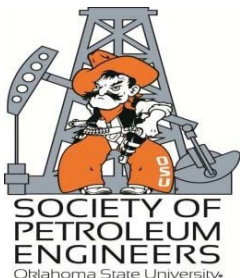
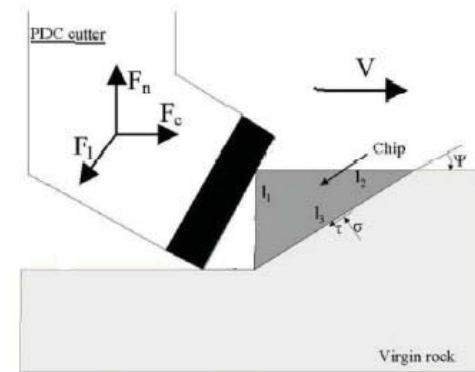
Mechanic Model of PDC Bits



Based on the experimental data, we can get the values of three force components (F_n , F_c , F_I) applied on the cutter. For example, F_n , F_c , F_I is 107.6, 89.4, 6.4 respectively when DOC of the cutter is 0.5

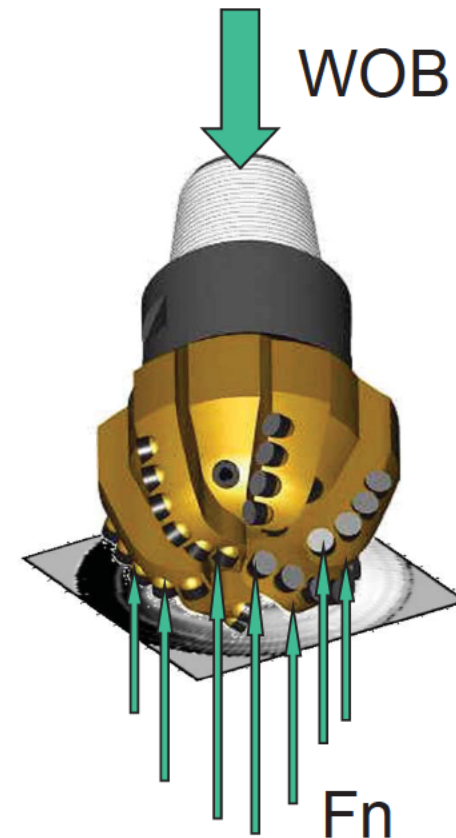
Crater Model of PDC Bits

Because the cutting action the crater volume is swept by the penetrated part of the cutter, which means the brittle property of the rock is not taken into account. As long as the cutter shape is known, we can get the crater shape and volume.



Simulation Mechanism of PDC Bits

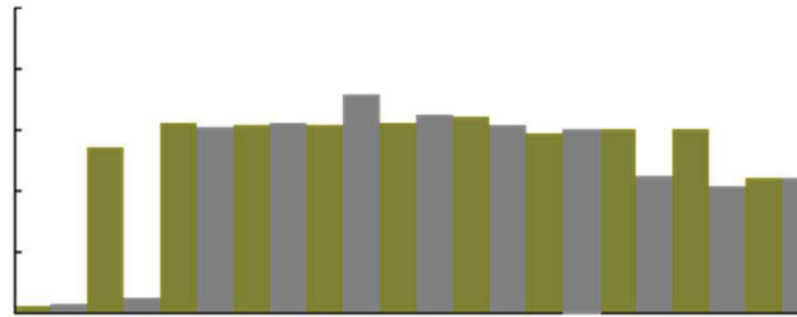
The simulation mechanism is the same as that of roller cone bit. That is the principle of vertical force equilibrium: WOB applied on the PDC bit is equal to the vertical resultant force of all cutters contacting the bottom hole.



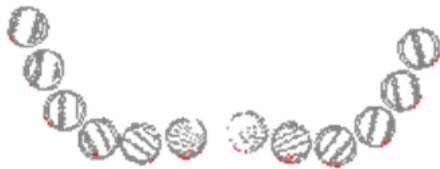
Plotting of PDC Bit Performance Software



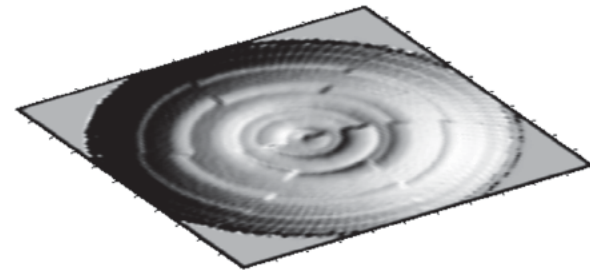
Instantaneous bottom pattern



Instantaneous Fn on all cutters
contacting the bottom hole



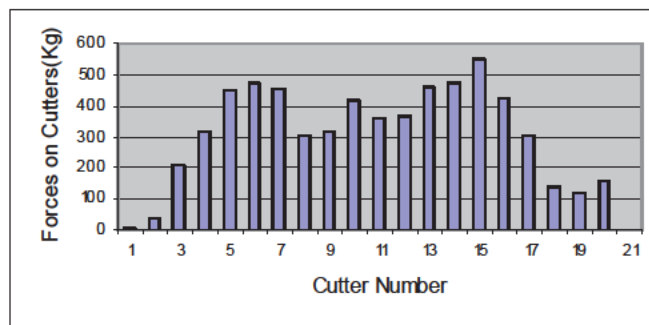
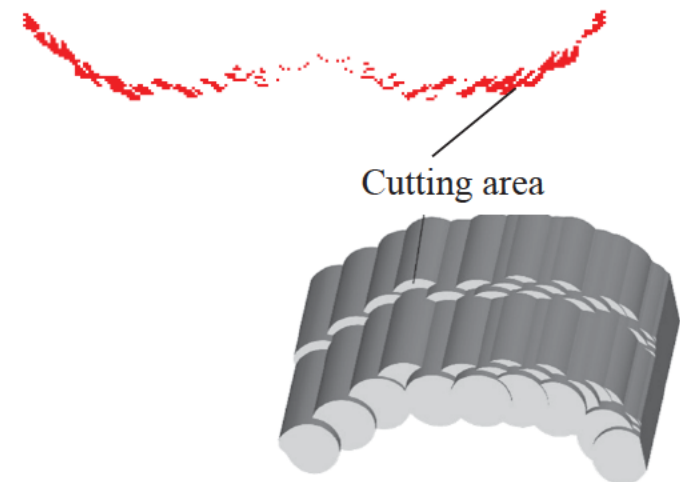
Bottom Hole coverage from all
cutters on the bit



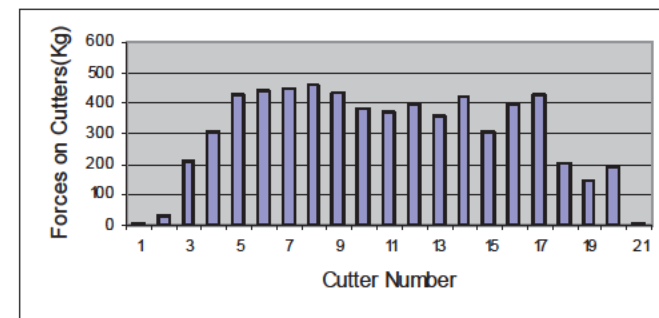
3D Simulated Bottom Hole Pattern

Functions of PDC Bit Performance Software

- Get forces on cutters, and make side force balance
- Calculate cutting area and volume
- ROP prediction, cutter wear analysis
- Analysis of vibration and whirling when coupled with drill string

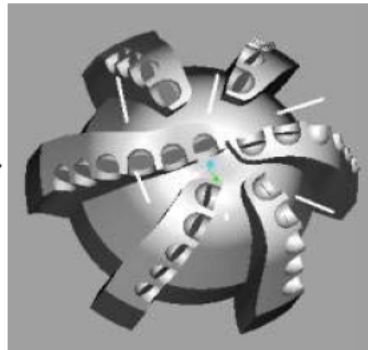
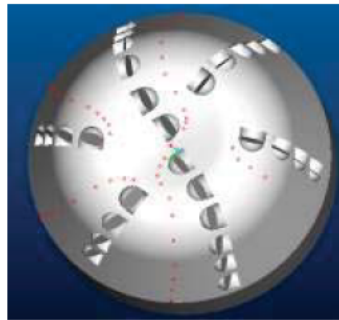
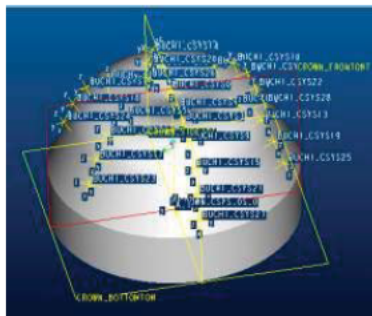


The forces on each cutter of a PDC bit before modification



The forces on each cutter of a PDC bit after modification

3D CAD of PDC Bits

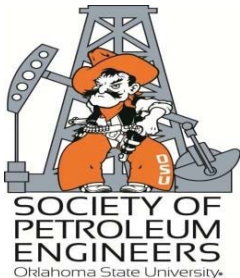


IADC Dull Bit Grading Application to PDC Bits

The International Association of Drilling Contractors has developed a standard methodology for describing used bits. This information is essential for detailed bit performance analysis.

The methodology is composed of an 8 character code that describes bit wear and the reason why the bit was pulled.

Cutting Structure				B	G	Remarks	
INNER ROWS	OUTER ROWS	DULL CHAR	LOCATION	BRNG/ SEALS	GAUGE 1/16"	OTHER CHAR	REASON PULLED



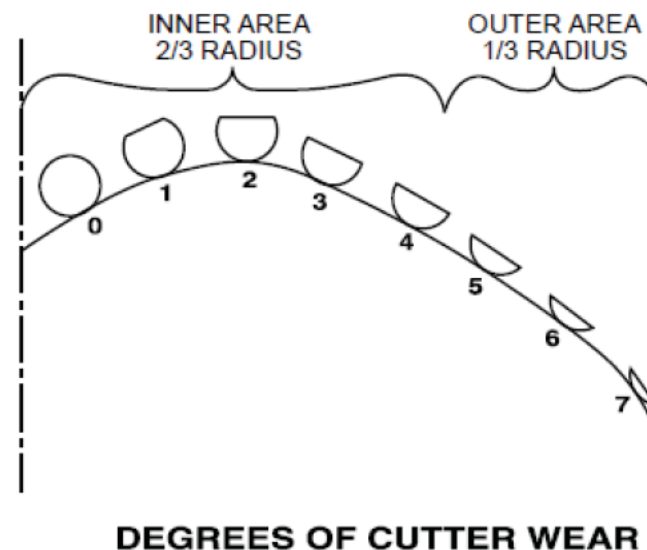
Grading of Worn PDC Bits

IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
2	6			X			

$$\frac{(4 + 3 + 2 + 1 + 0)}{5} = 2$$

$$\frac{(5 + 6 + 7)}{3} = 6$$

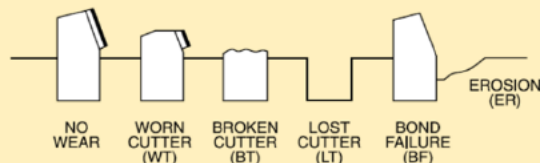
The cutting structure is graded from 0 to 8 depending on the proportion of cutting structure lost (0 = Intact, 8 = 100% worn).



Grading of Worn PDC Bits

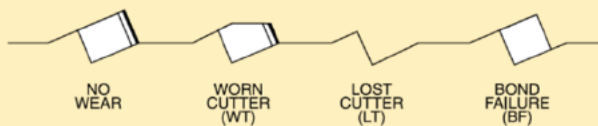
IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
		WT		X		RO	

FIGURE 2A. STUD CUTTERS



WEAR CHARACTERISTICS: POST OR STUD CUTTERS

FIGURE 2B. CYLINDER CUTTERS



WEAR CHARACTERISTICS: CYLINDER CUTTERS

*BC - Broken Cone
 BF - Bond Failure
 BT - Broken Teeth/Cutters
 BU - Balled Up
 *CC - Cracked Cone
 *CD - Cone Dragged
 CI - Cone Interference
 CR - Cored
 CT - Chipped Teeth/Cutters
 ER - Erosion
 FC - Flat Crested Wear
 HC - Heat Checking
 JD - Junk Damage
 *LC - Lost Cone
 LN - Lost Nozzle
 LT - Lost Teeth/Cutters
 NO - No Major/Other Dull Characteristics
 NR - Not Rerunnable
 OC - Off-Center Wear
 PB - Pinched Bit
 PN - Plugged Nozzle/Flow Passage
 RG - Rounded Gauge
 RO - Ring Out
 RR - Rerunnable
 SD - Shirttail Damage
 SS - Self Sharpening Wear
 TR - Tracking
 WO - Washed Out Bit
 WT - Worn Teeth/Cutters

**Show cone number(s) under "Location".*

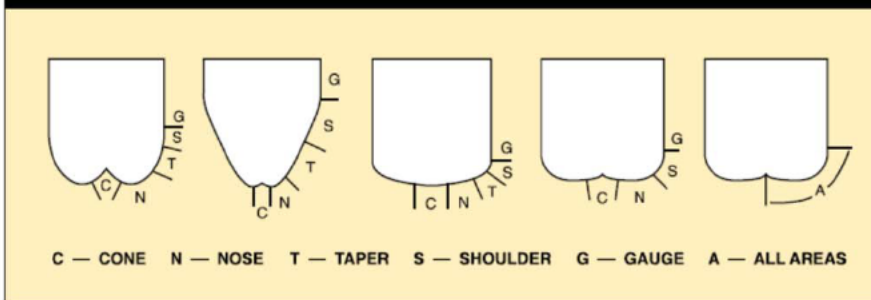
NOTE: If no "Dull Characteristic" is visible, mark this space "No". If no "Other Characteristic" is visible, mark this space "No".

BHA - Change Bottomhole Assembly
 DMF - Downhole Motor Failure
 DSF - Drillstring Failure
 DST - Drill Stem Test
 DTF - Downhole Tool Failure
 LOG - Run Logs
 RIG - Rig Repair
 CM - Condition Mud
 CP - Core Point
 DP - Drill Plug
 FM - Formation Change
 HP - Hole Problems
 HR - Hours
 PP - Pump Pressure
 PR - Penetration Rate
 TD - Total Depth/CSG Depth
 TQ - Torque
 TW - Twist Off
 WC - Weather Conditions
 WO - Washout Drillstring

Grading of Worn PDC Bits

IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
			N	X	I		

FIGURE 3. FIXED CUTTER BIT PROFILES



Bearing Seals

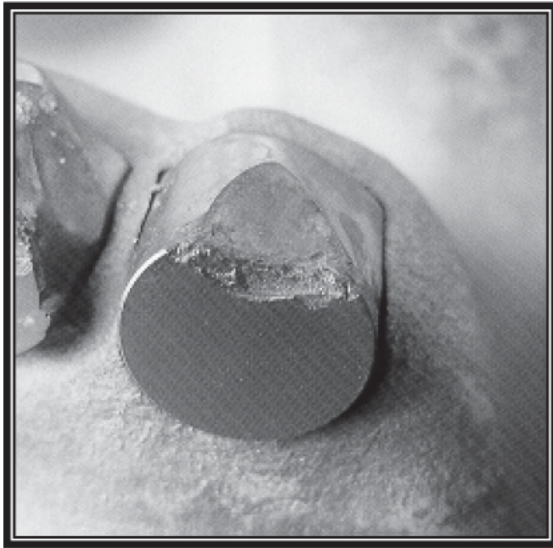
This space is used only for roller cone bits. Therefore, it will always be marked "X" when grading fixed cutter bits.

FIGURE 4. GAUGE CONDITION

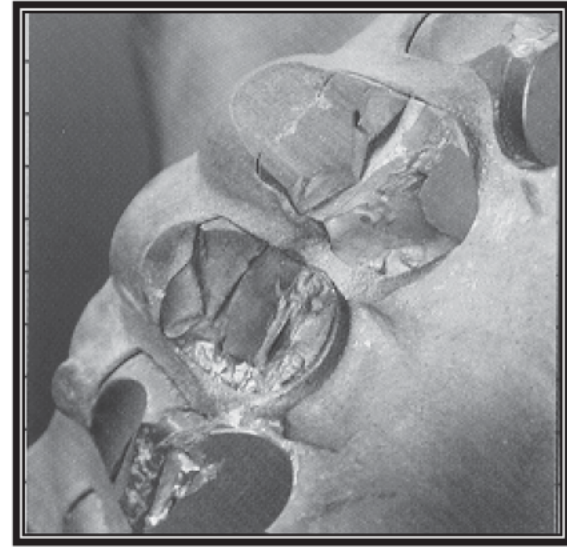
Code	Explanation
I	In Gauge
1/16	Undergauge up to 1/16"
2/16	Undergauge 1/16" to 1/8"
3/16	Undergauge 1/8" to 3/16"
4/16	Undergauge 3/16" to 1/4"

Understand the components of profiles?

Grading of Worn PDC Bits

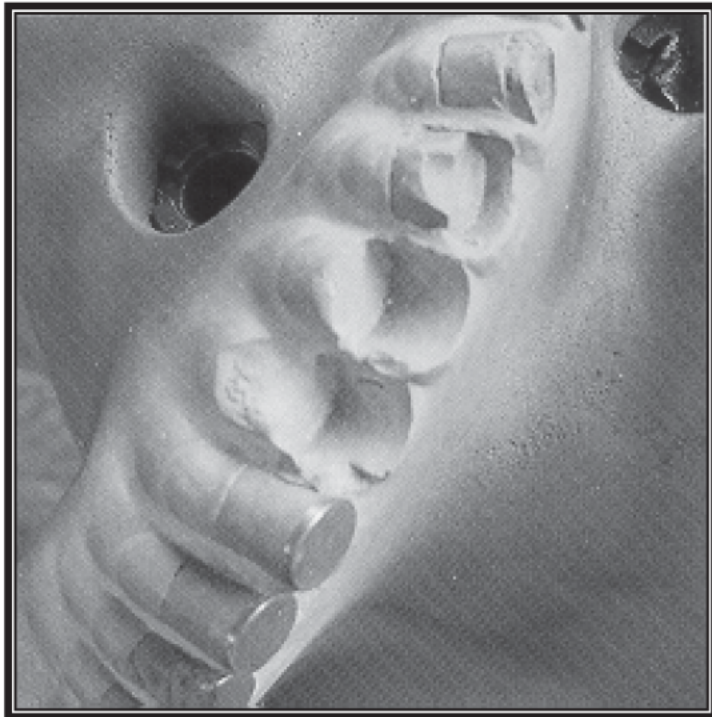


CT - Chipped Cutter
Less than 1/3 of cutting element is gone



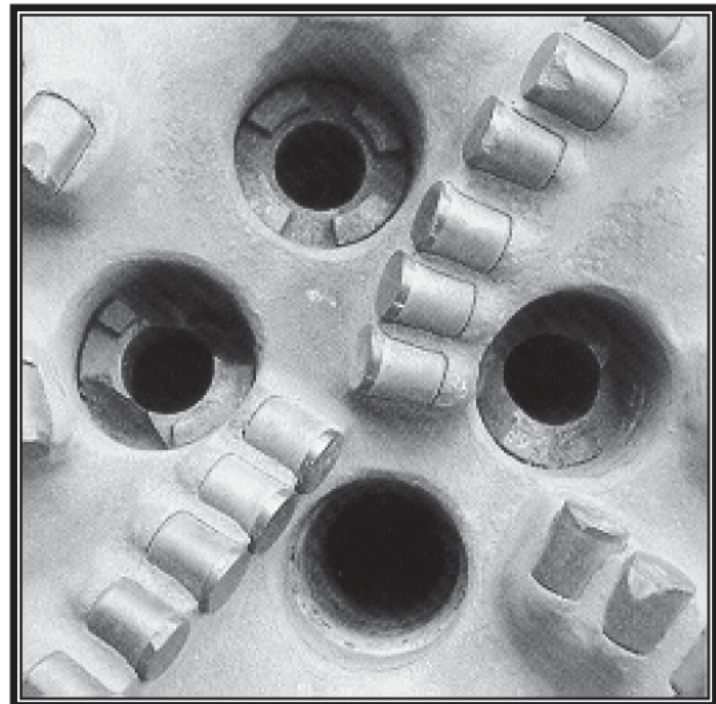
BT - Broken Cutter
More than 1/3 of cutting element is broken to the substrate

Grading of Worn PDC Bits



LT - Lost Cutter

Bit is missing one or more cutters



LN - Lost Nozzle

Bit is missing one or more nozzles

Grading of Worn PDC Bits

IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
3	4	WT	A	X	I	BU	BHA

IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
0	0	NO	A	X	I	NO	DTF
Run 2							
0	0	NO	A	X	I	NO	DTF
Run 3							
2	2	NO	A	X	I	NO	BHA
Run 4							
5	4	BT	A	X	I	ER	DTF

Tool Failure

Grading of Worn PDC Bits



0 1 WT S XXX IN NO TD

What does XXX mean?

Grading of Worn PDC Bits



IADC DULL GRADING SYSTEM CHART							
Cutting Structure				B	G	Remarks	
Inner Rows	Outer Rows	Dull Characteristics	Location	Bearing Seals	Gauge 1/16"	Other Characteristics	Reason Pulled
0	1	WT	S	XXX	IN	NO	TD

Worn Teeth
Shoulder

Explain "0 1 WT S XXX IN NO TD" ?

Grading of Worn PDC Bits

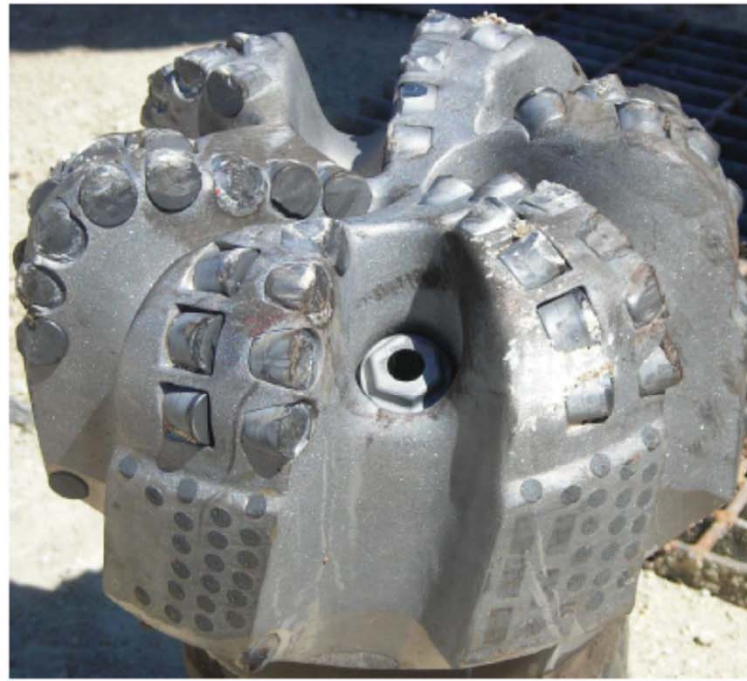


1 3 WT S XXX IN CT TD

Chipped Teeth



Grading of Worn PDC Bits



3 6 BC N XXX IN SP PR

Broken Cutter

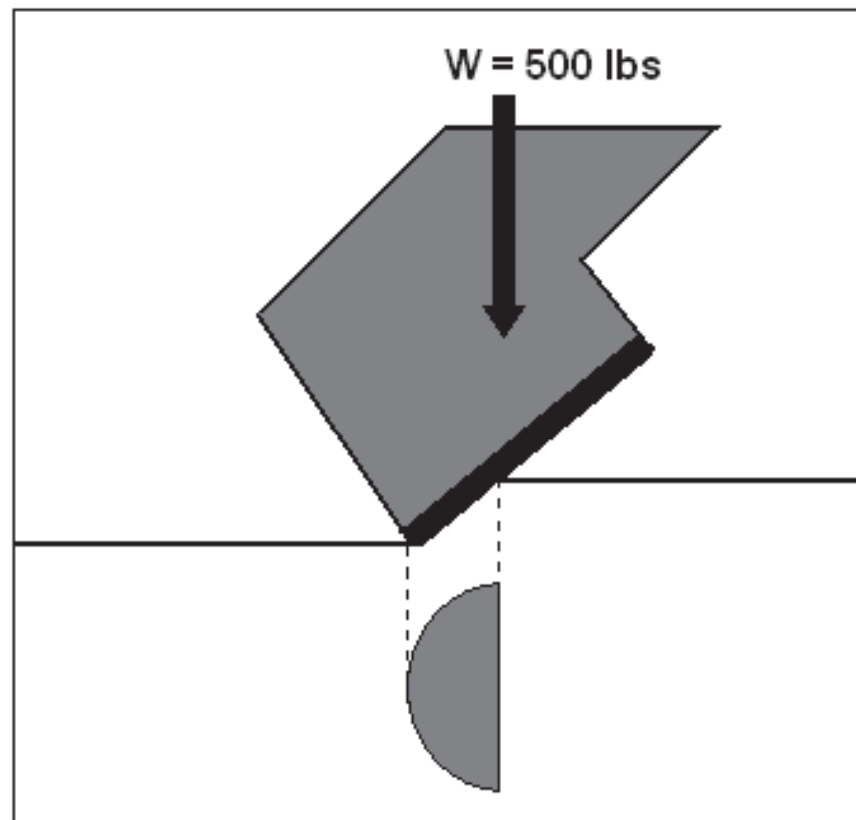
?

The “Optimizer” PDC Model

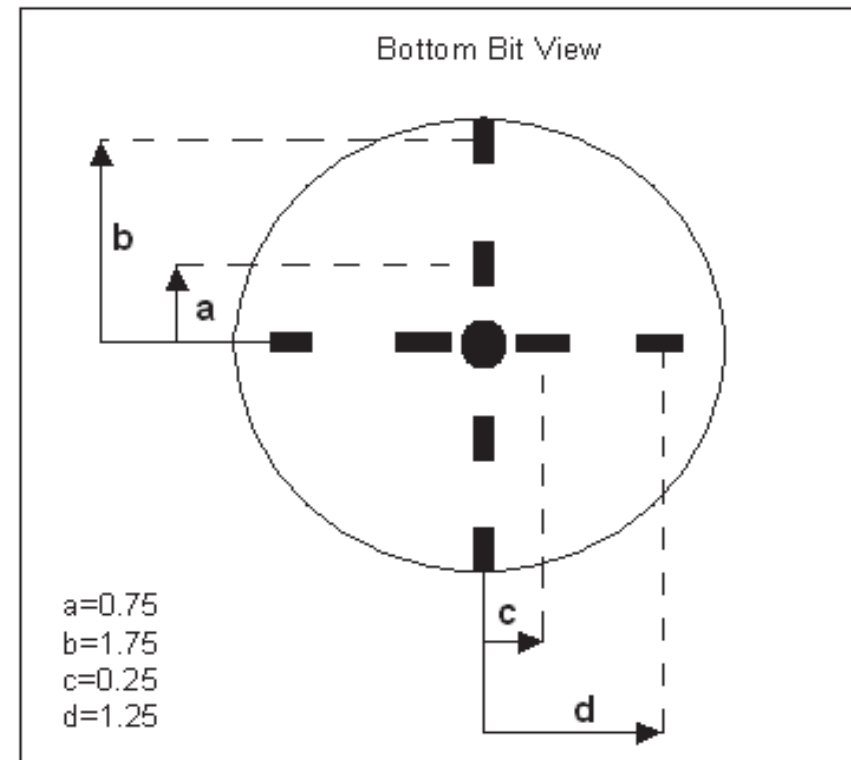
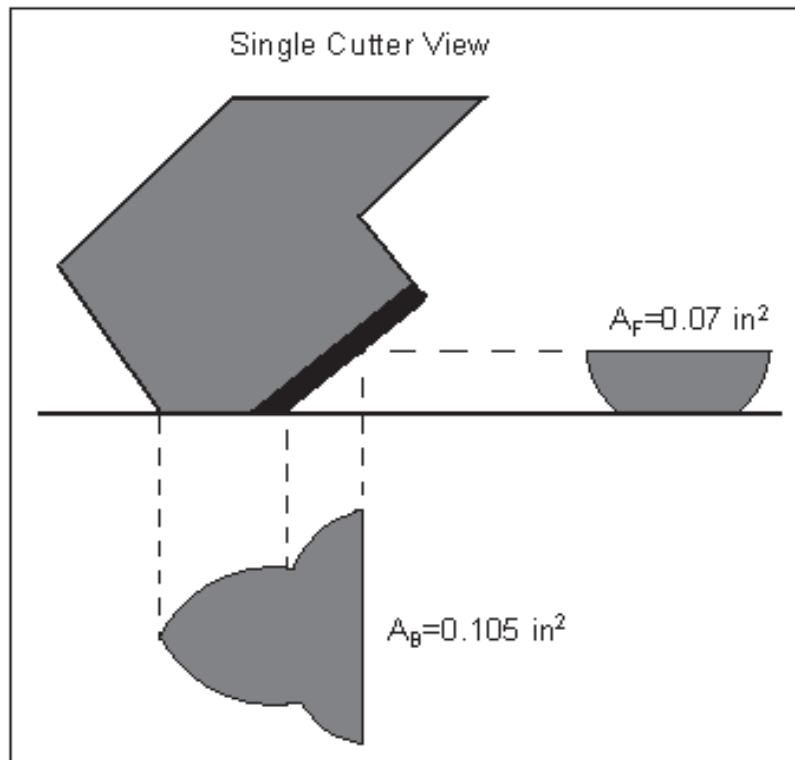
- Drill-ahead model.
- Developed based in cutter rock interaction.
- Vertical force balance.
- Lateral material balance concept.
- Averaged cutter performance.
- Cutter wear effect on ROP.
- Detailed PDC cutter information.
- Backup cutters with exposure.
- Universal apparent (unconfined) rock strength (ARSL).

The PDS PDC Model

➤ **Single cutter vertical force balance**



The “Optimizer” PDC Model Sample Illustration



The “Optimizer” PDC Model

Sample Calculation

ARS

$$\sigma = \frac{W_B}{A_B \cdot (8)} \Rightarrow$$

WOB

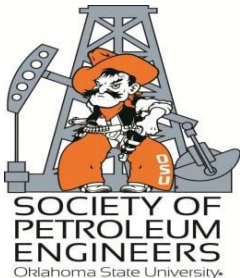
$$\begin{aligned} W_B &= A_B \cdot \sigma \cdot (8) = (0.105 \text{ in}^2) \cdot (10,000 \text{ psi}) \cdot 8 \\ &= 1050 \text{ lbs} \cdot 8 = 8400 \text{ lbs} \end{aligned}$$

Torque

$$\begin{aligned} T &= W_F \cdot d \\ &= W_F \cdot [(0.25" + 1.25") \cdot (2) + (0.75" + 1.75") \cdot (2)] \\ &= A_F \cdot \sigma \cdot 8 \\ &= (0.07) \cdot (10,000) \cdot (8) \\ &= 5600 \text{ lbs} \cdot \text{in} = 465 \text{ lbs} \cdot \text{ft} \end{aligned}$$

PDC

*So – lets do this in class – just
fill in the table values!*



The ROP Models

Sensitivity Study with “ShortyPDC”

- **The sensitivity study is performed with a short ARSL (12 meter) to illustrate the effect of different parameters on ROP.**
- **The ARSL will have constant input parameters from one short bit run.**
- **The bits will initially have no or little wear.**
- **The ARSL is created from three input files and is vertical. There will be performed one study for each bit type. (PDC and NDB)**
- **The sensitivity studies include bit design, wear and operating parameters.**

Sensitivity Study with “ShortyPDC”

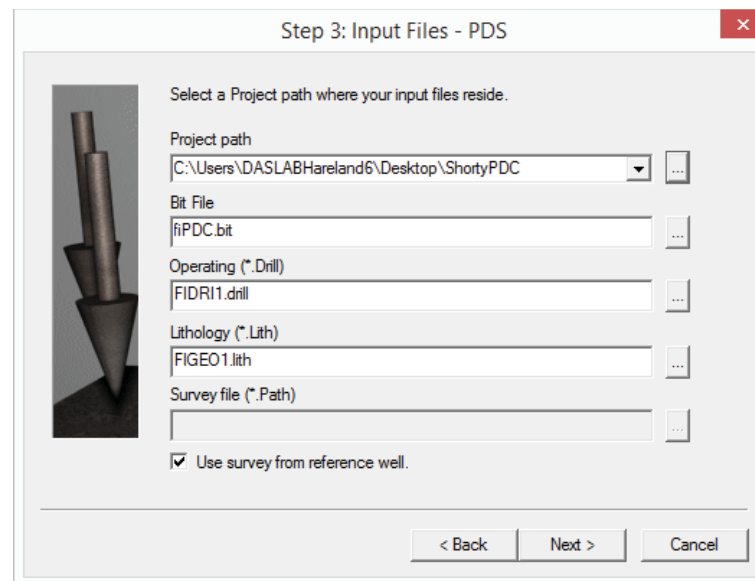
The ARSL Input Files

- The ARSL is created from three input files and is vertical.
- The drilling lithology file is figeo1.lith and contains the geology composition and pore pressure.
- The drilling parameter file is fidri1.drill and contains the ROP, operational parameters, flowrate and mud weight.
- There are three different bit files dependent on the type of bit used to generate the ARSL.
- The drag bit files are named fiNDB.bit and fiPDC.bit.



Sensitivity Study with “ShortyPDC”

- Start “Optimizer” and use default rig rate, times and parameter bounds.
- Locate the “ShortyPDC” project at:
- Desktop/ShortyPDC
- Then click on OK.



Sensitivity Study with “ShortyPDC”

The ARSL Input Files - fiPDC.bit

(ROP=30 m/hr - Base Case)

[123456]			
Bit Type = pdc			
IADC Code = 999			
Bit Diameter = 12.25			
TVD In = 2859.00			
TVD Out = 2871.00			
MD In = 2859.00			
MD Out = 2871.00			
Wear In = 0.0			
Wear Out = 0.001			
Cost = 48062			
DHM Cost = 0			
Manufacturer = N/A (converted file)			
Bit Description = N/A (converted file)			
Nozzle1 = 14			
Nozzle2 = 14			
Nozzle3 = 14			
Nozzle4 = 14			
Nozzle5 = 14			
Nozzle6 = 14			
Nozzle7 = 0			
Nozzle8 = 0			
Primary Number of Cutters = 69			
Backup Number of Cutters = 0			
Primary Cutter Size = 0.5			
Backup Cutter Size = 0.0			
Primary Backrake = 20			
Backup Backrake = 0			
Primary Siderake = 15			
Backup Siderake = 0			
Number of Blades = 6			
Junk Slot Area = 28			
Thickness = .02756			
Exposure = 0			
Distance = 0			



Sensitivity Study with “ShortyPDC”

- **The parametric study will see the effect on ROP by changing the different parameters.**
- **The study is performed by changing one parameter at the time and maintaining all other parameters constant.**
- **This will for the PDC bits include operational, bit and cutter design, bit size and wear.**

Sensitivity Study with “ShortyPDC”

➤ Note the ROP is here 30 m/hr.

Simulation Control Sheet

Secti...	Run	BitID	From	To	Diff	WOB	RPM	Flow...	PV	MW	Bit ...	Total...	ROP	Cost...	Drill...	Mudt...
001	001	001 -...	2859.0	2871.0	12.0	10.0	150.0	2400.0	44.0	1.65	0.0	0.0	30.00	9596...	Rotary	Oil

View Plot
Bitinfo
Merge With Previous
Set MWP
Set WOB/RPM
Hydraulics
AI
Hide

Run
Split Section
Merge With Next
Clear MWP
Clear WOB/RPM
Parameters
Copy To New Simulation
Export Sim

Simulation results summary : [Cost in thousand dollars unless stated]:

Sim	Bit (\$)	Trip (\$)	Connect...	DHMoto...	Rotating...	Total (\$)	Cost(\$/m)	Time (h)
000	48.1	72.4	0.9	0.0	3.3	124.8	9596.7	0.4
001	New							

Average ROP for entire well: 30.00

Simulation completed :

Sensitivity Study with “ShortyPDC”

- To evaluate the bit hydraulics click on the hydraulics box (note 6 nozzles).
- Use can here evaluate different nozzle configurations but not change them.

The screenshot shows a software dialog box titled "Bit Hydraulics" with a close button (X) in the top right corner. The dialog is organized into three main sections: "Bit properties", "Fluid properties", and "Results".

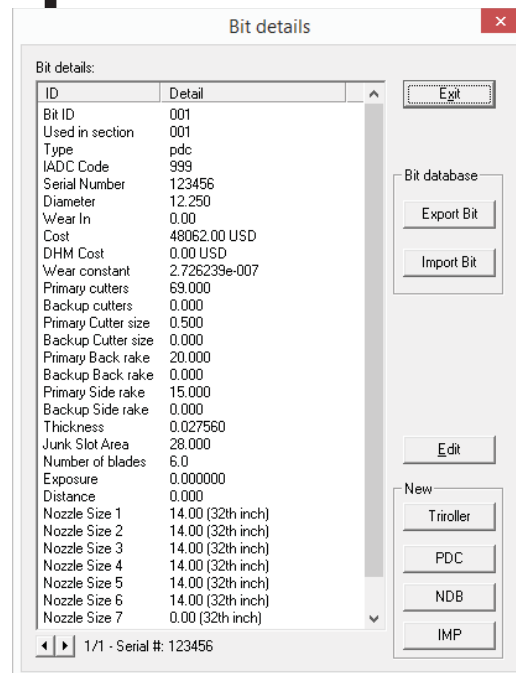
- Bit properties:**
 - Bit size: 12.250 [in]
 - Nozzles size: A 2x4 grid of spinners. The top row has values 14, 14, 14, and 0. The bottom row has values 14, 14, 14, and 0. To the right of the grid is the unit [1/32 in].
 - Discharge coefficient: 100 [%]
- Fluid properties:**
 - Flowrate: 2400
 - Mud Weight: 1.65
- Results:**
 - Bit Pressure Drop: 565.43 [psi]
 - HSI: 1.775 [HSI]

At the bottom of the dialog are two buttons: "OK" and "Cancel".



Sensitivity Study with “ShortyPDC”

- To change the bit nozzles click on the “Bitinfo” box.
- This will display the bit details and to change the bit parameters click on “Edit”



Sensitivity Study with “ShortyPDC”

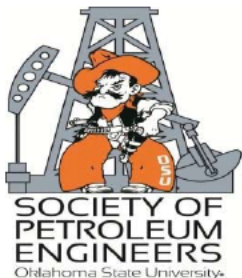
- Here you change the nozzles or other bit design properties, then click “OK” then “OK” on the bit details.

Bit Details PDC

IADC Code	999					Hydraulics (32th inch)				
Serial Number	123456		#	Backrake (Deg)	Siderake (Deg)	Diameter (inch)	Nozzle 1	14	Nozzle 5	14
Diameter	12.25	Primary Cutters	69	20	15	0.5	Nozzle 2	14	Nozzle 6	14
Wear In	0	Backup Cutters	0	0	0	0	Nozzle 3	14	Nozzle 7	0
Wear Out	0.001						Nozzle 4	14	Nozzle 8	0
Cost	48062	Number Of Blades	6	Exposure(inch)	0		Total Flow Area(in.^2) 0.90			
DHM Cost	0	Junk Slot Area(inch^2)	28	Distance(inch)	0					
Wear Constant	2.726e-007	Thickness(inch)	0.02756							
							OK		Cancel	

Sensitivity Study with “ShortyPDC”

				Base Case		
Parameter						
WOB	4	7	10	14	17	
ROP			30		38.71	
RPM	50	100	150	200	250	
ROP	14.55		30			
HP/Inch**2	0.8	1.2	1.78	2.5	4	
ROP			30			
Nozzle Size	6*12	6*13	6*14	6*15	6*16	
ROP			30			
Flowrate	2000	2200	2400	2600	2800	
ROP			30			
Mud Weight	1.55	1.6	1.65	1.7	1.75	
ROP	32.07		30			
Plastic Viscosity	24	34	44	54	64	
ROP			30			
Oil VS Water			Oil		WTR	
ROP			30			

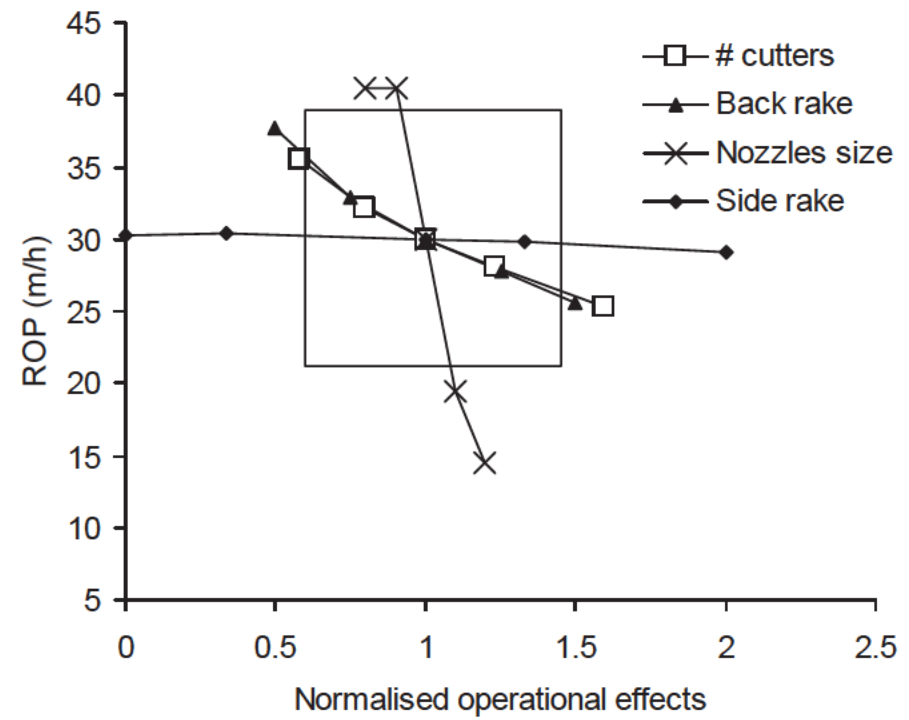
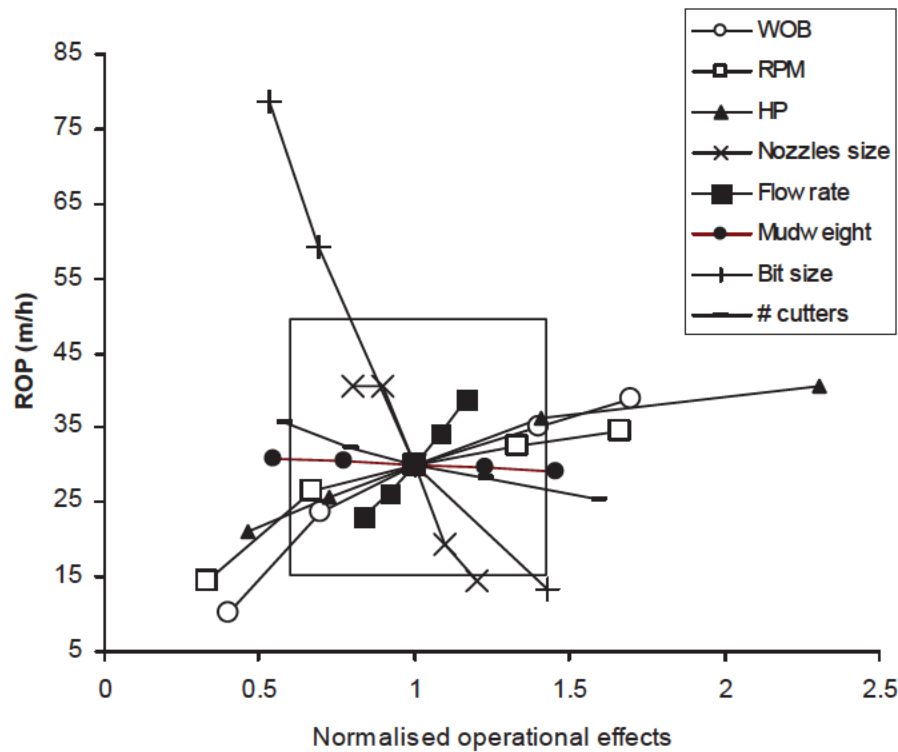


Sensitivity Study with “ShortyPDC”

Bit Properties										
						1*27				
Bit Size (HSi constant?)					6.5	8.5	12.25	17.5		
							30			
Number of Primary Cutters					40	55	69	85	110	
					35.57		30			
Number of Blades					4	5	6	7	8	
							30			
Primary Cutters Backrake					10	15	20	25	30	
							30		25.6	
Primary Cutters Siderake					0	5	15	20	30	
							30			
Primary Cutters PDC Layer Thickness					0.01	0.018	0.0277	0.06	0.16	
					30		30			
Junk Slot Area					20	24	28	34	40	
					0	0	30	0	37.9	
We will look at backup cutters later.										

Sensitivity Study

Sample Analysis-STAR plots



Sensitivity Study with “ShortyPDC”

- Change the base case WOB to 5 tons, the ROP is now 14.29 m/hr.

Bit Size (HSI Constant?)			6.5	8.5	12.25	17.5	
					14.29		
Number of Primary Cutters			40	55	69	85	110
					14.29		
Number of Blades			4	5	6	7	8
					14.29		
Primary Cutters Backrake			10	15	20	25	30
					14.29		
Primary Cutters Siderake			0	5	15	20	30
					14.29		
Primary Cutters PDC Layer Thickness			0.01	0.018	0.0277	0.06	0.16
					14.29		
Junk Slot Area			20	24	28	34	40
					14.29		
HP/Inch**2			0.8	1.2	1.777	2.5	4
					14.29		
Mud Weight			1.55	1.6	1.65	1.7	1.75
					14.29		11.4

Sensitivity Study Conclusions

- **The hydraulics effect is larger when the base case ROP is high.**
- **When base case ROP is lower the design parameters has a larger effect on ROP.**
- **The mud weight effect is included both in confining the rock and increasing the hydraulics.**
- **All the operating and bit design effects are integrated and must be carefully evaluated for each application.**
- **Cutter PDC thickness and backup cutters will be evaluated later because this bit does not have any wear.**



Handout#6

NDB Bits

Diamond Qualities:

- Industrial – Now #1!
- Congo rounds
- Processed Congo
- West African
- Octahedron
- Cubes
- Carbonado

Cutting Action of Diamonds:

- Plowing
- Shearing (cut/chip)
- Dislodging (to remove or force out from a position or dwelling previously occupied)

NDB Design Parameters:

1. Crown profile (round, tapered, extended, flat)
2. Fluid courses (radial, cross pad)
3. Diamond patterns (single row, interference, circle set, staggered circle set)

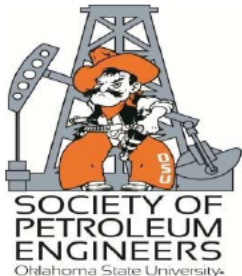
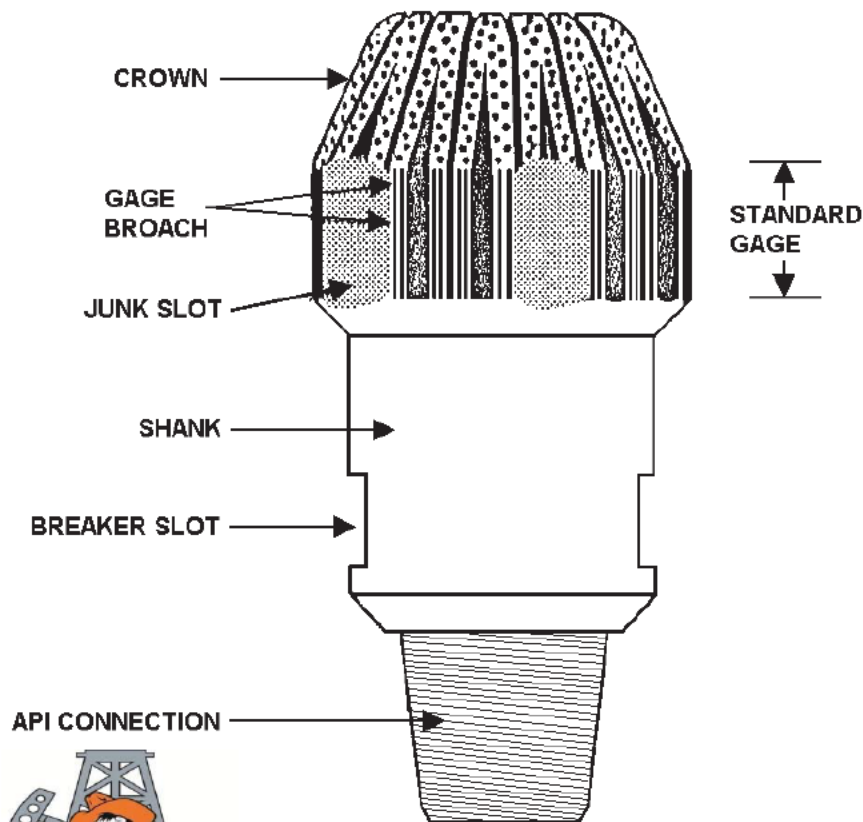
Applications of NDB:

Situations that indicate probable need for NDB

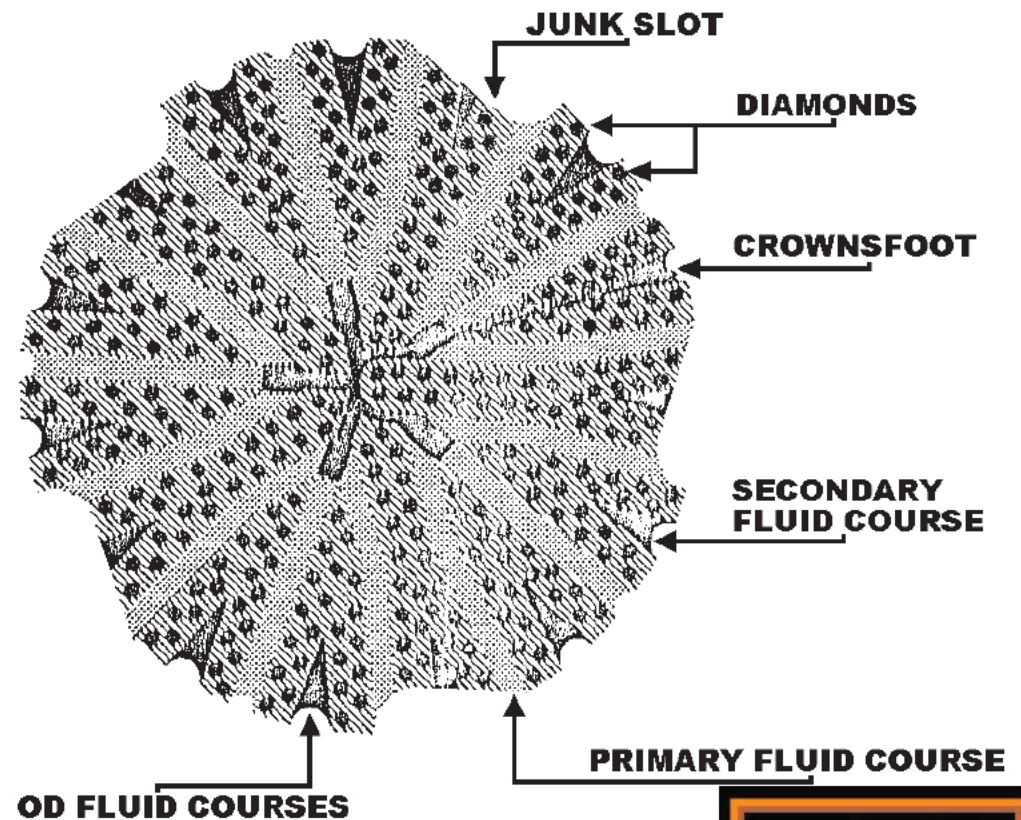
1. Very short bit life
2. Low ROP
3. High speed motor or turbine applications

NDB General

Side View of Diamond Bit



Top View of Diamond Bit



What is the function of junk slot?



Fixed Cutter Bits (ND Bits)

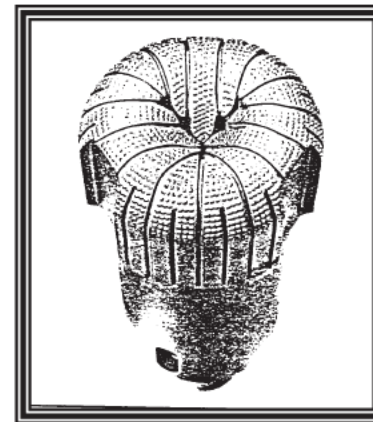
ND Bits

- Best for hard non-brittle formations
- The face or crown of the bit consists of many diamonds set in a tungsten carbide matrix
- Fluid courses are provided in the matrix to direct the flow of drilling fluid over the face of the bit.



Soft Formation

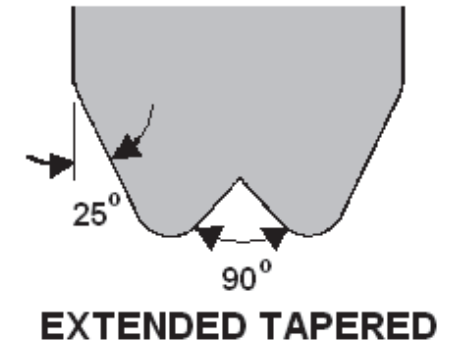
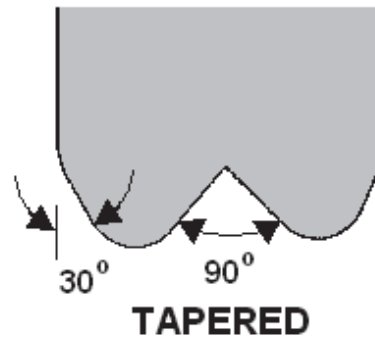
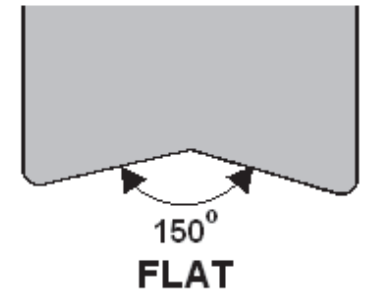
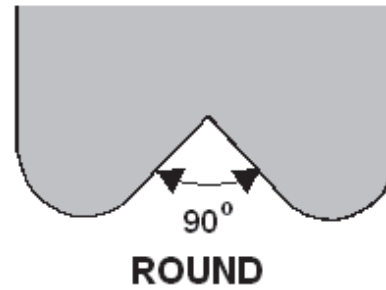
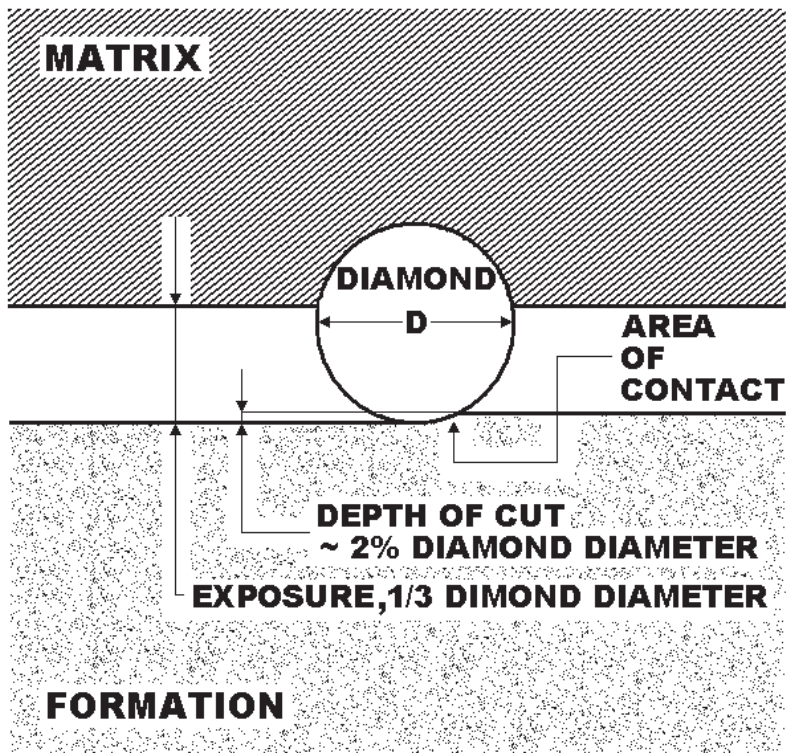
- Larger diamonds
- Fewer diamonds
- Pointed nose



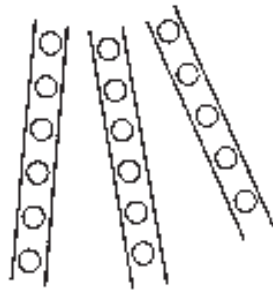
Hard Formation

- Smaller diamonds
- More diamonds
- Flatter nose

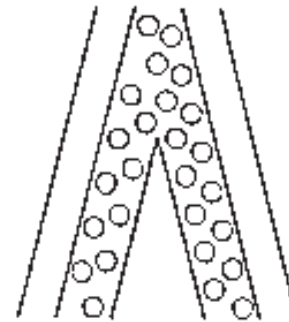
NDB General



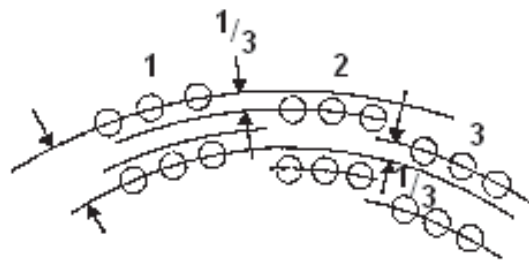
NDB General



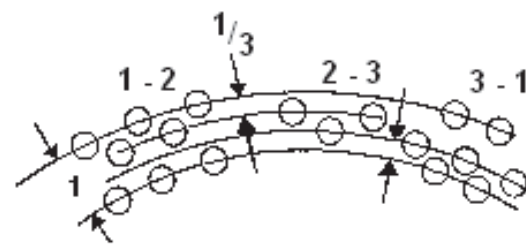
**Constant width diamond pads
expanded width fluid courses**



**Constant width diamond pads
constant width fluid courses**



CIRCLE SET



STAGGERED

NDBs- Model History

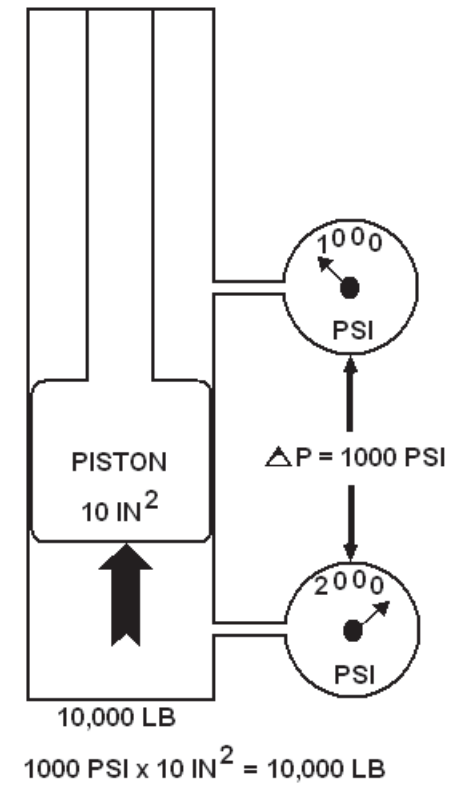
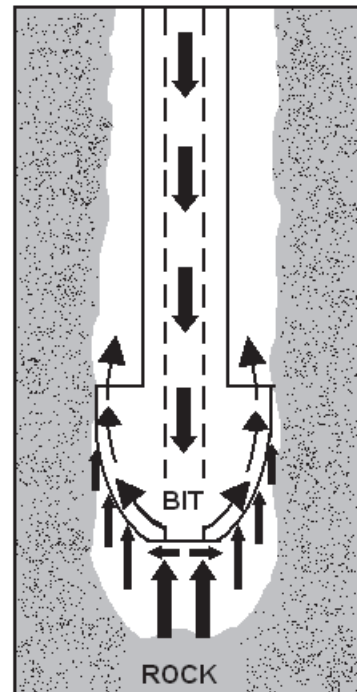
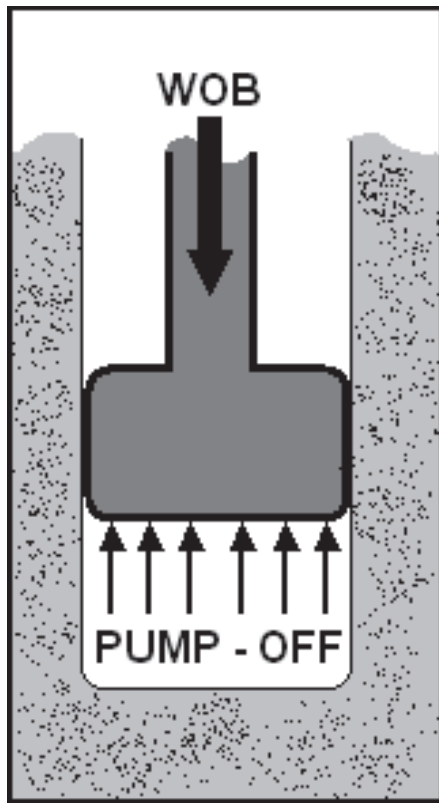
- **NDB modeling has been attempted back to the early 60's by Apple and Rowley, but with little practical applications.**
- **The “Optimizer” uses single diamond loading and includes the pump-off properties of the NDB bits.**
- **To be able to model the NDB bit performance accurate pump-off information is a must.**
- **The “Optimizer” model includes single diamond/rock interaction and diamond wear, and is verified with laboratory and field data.**



The “Optimizer” NDB Model

- **Drill-ahead model.**
- **Developed based in diamond rock interaction.**
- **Vertical force balance.**
- **Lateral material balance concept.**
- **Averaged diamond performance.**
- **Diamond wear effect on ROP.**
- **Detailed diamond information.**
- **Pump-off properties.**
- **Universal apparent (confined) rock strength (ARSL).**

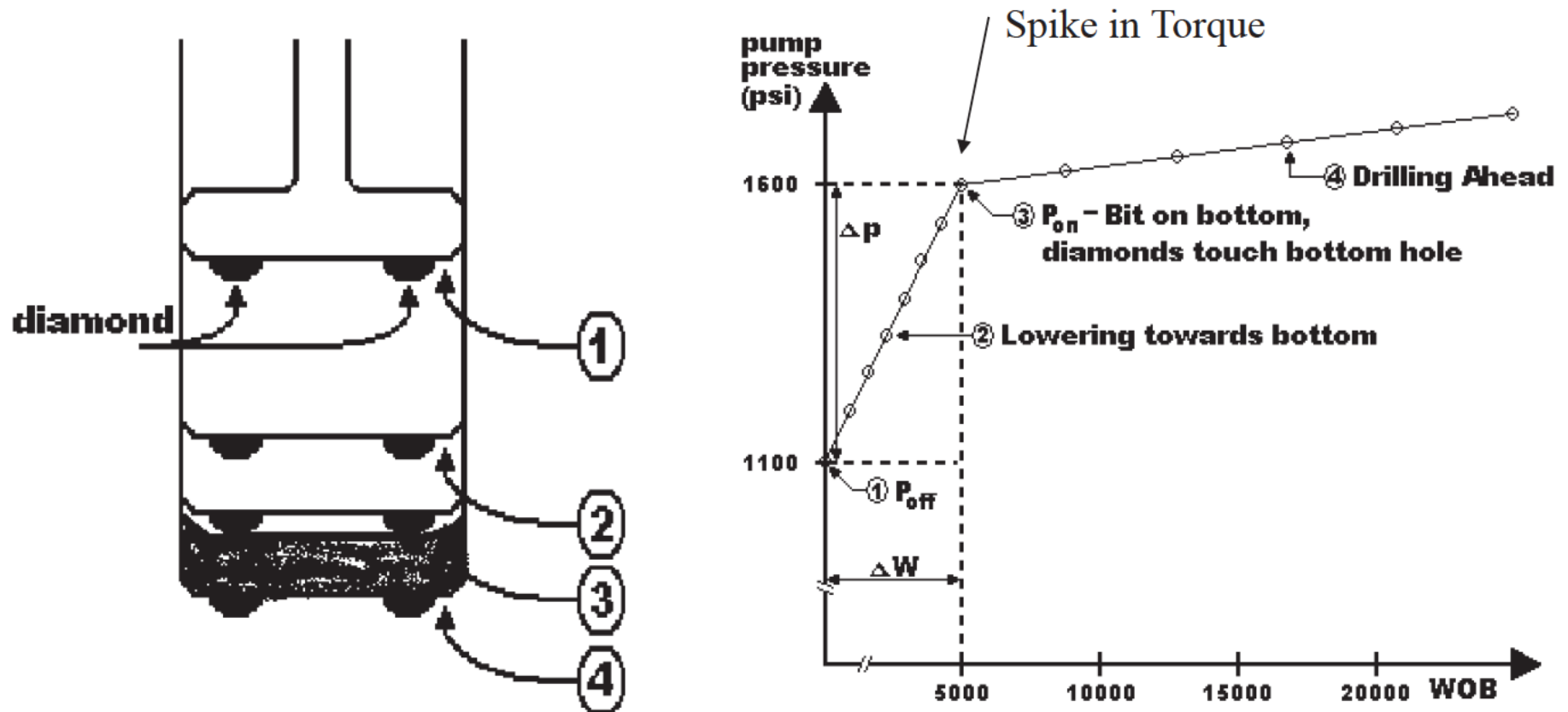
Pump-Off Modeling



Pump-Off Test and Modeling

Test done in the field!

Properties change during a bit run!



$$WOB_{actual} = WOB_{applied} - A_{po} * \Delta PP$$

Pump-Off Modeling (example Flowrate=869 gpm)

Pump - Off Area

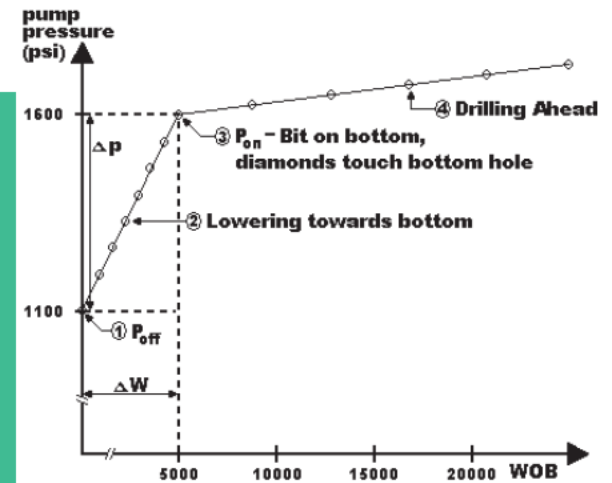
$$A_{PO} = \frac{\Delta WOB(lbs)}{\Delta PP(psi)} \Rightarrow$$

$$A_{PO} = \frac{5000}{(1600 - 1100)} = 10 \text{ in}^2$$

Apparent Nozzle Area

$$A_{App} = \sqrt{\frac{(Flowrate(GPM)) * (Flowrate(GPM)) * Density(ppg)}{12031 * \Delta PP(psi)}}$$

$$A_{App} = \sqrt{\frac{(869) * (869) * (16)}{(12031 * 500)}} = 2.0 \text{ in}^2$$

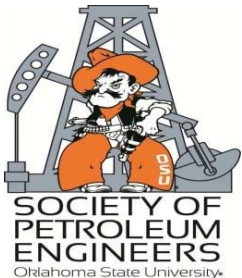


$$WOB_{actual} = WOB_{applied} - A_{po} * \Delta PP$$



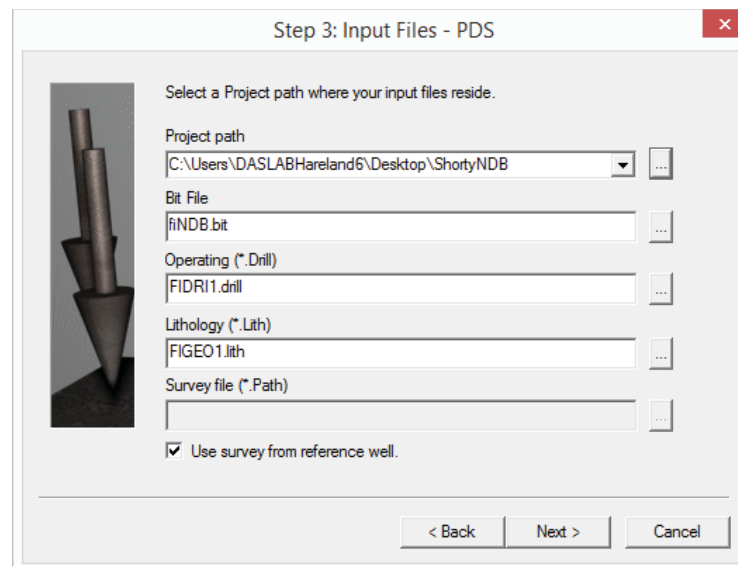
NDB

***So – lets do this in class – just
fill in the table values!***



Sensitivity Study with “ShortyNDB”

- Start “optimizer” and use default rig rate, times and parameter bounds.
- Locate the “ShortyNDB” project at:
- Desktop\ShortyNDB
- Then click on OK.



I. Sensitivity Study with “Shorty The ARSL Input Files - fiNDB.bit (BitOD=8,5”, Flow rate=1200 lpm, ROP=5 m/hr, RPM=250)

[123456]				
Bit Type = NDB				
IADC Code = 911				
Bit Diameter = 8.5				
TVD In = 2859				
TVD Out = 2871				
MD In = 2859				
MD Out = 2871				
Wear In = 0				
Wear Out = 0.001				
Cost = 58775				
DHM Cost = 0				
Manufacturer = some				
Bit Description = ndbb				
Number of Diamonds = 1000				
Diamond Size = 0.072				
Pump Off Area = 8.2				
Apparent Flow Area = 1.35				

Sensitivity Study with “ShortyNDB”

- **The parametric study will see the effect on ROP by changing the different parameters.**
- **The study is performed by changing one parameter at the time and maintaining all other parameters constant.**
- **This will for the NDB bits include operational, bit and pump-off designs, bit size and wear.**

Sensitivity Study with “ShortyNDB”

Operational								
WOB				5	7	10	15	20
				0	0	5	0	9.12
RPM				100	150	250	300	400
				0	0	5	0	0
Flowrate				800	1000	1200	1400	1600
				0	0	5	0	4.87
Mud Weight				1.55	1.6	1.65	1.7	1.75
				0	0	5	0	0
Spurt Loss (Plastic Viscosity)				24	34	44	54	64
				0	0	5	0	5

Sensitivity Study with “ShortyNDB”

Bit Details NDB

IADC Code

911

Number Of Diamonds

1000

Serial Number

123456

Diamond Size

0.072

Diameter

8.5

Pump Off Area

8.2

Wear In

0

Out

0.001

Apparent Flow Area

1.35

Cost

58775

DHM Cost

0

Wear Constant

3.226e-007

OK

Cancel

Bit Properties									
Bit Size (Pump-off Properties Change) !?						6.5	8.5	12.25	
						6.54	5	0	
Number of Diamonds				800	900		1000	1100	1200
				0	0		5	0	4.6
Diamond Size				0.05	0.06		0.072	0.1	0.15
				0	0		5	0	2.48

The ROP Models

Pump-Off Properties

- | ➤ <u>Increase In</u> | <u>ROP</u> |
|------------------------------|------------|
| ➤ Apparent Nozzle Area (NDB) | Inc. |
| ➤ Pump Off Area (NDB) | Dec. |
| ➤ Bit Wear (NDB) | Inc./Dec. |

Sensitivity Study with “ShortyNDB”

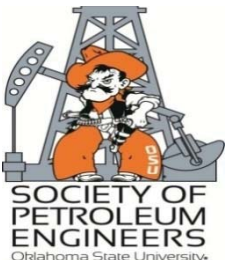
Pump-Off Properties									
Apparent Nozzle Area			0.2	0.3	0.8	1	1.35	1.5	2
			0	1.54	0	0	5	0	0
Pump Off Area					5	7	8.2	10	12
					0	0	5	0	4.92

If Apparent Nozzle Area was different?
Larger/Smaller effect

NDB

Sensitivity Study Conclusions

- **Pump-Off must be understood.**
- **Diamond size and number of diamond is critical.**
- **The diamond geometry has a large effect on ROP.**
- **Currently the NDB model can be used for impregnated bit but with care. (Small amount of small diamonds, pump of area of 0.0, bit wear must be handled separately)**



Assignment Drilling Simulation

Due October 10

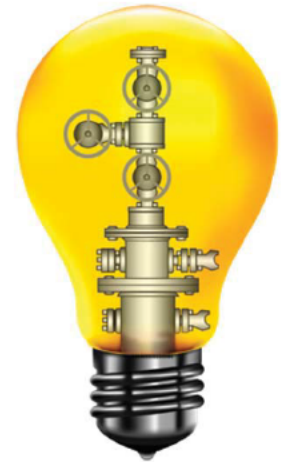
Title: “The Optimizer” – Drag Bit ROP Model Sensitivity Analysis

Drag Bits

- A. Construct Star Plots (using percent parameter sensitivities) from slide 41,42 and 44 for PDC bits
- B. What is the PDC ROP reduction if a cutter is worn 25 percent, 50 percent and 75 percent (IADC bit wear 2, 4 and 6)?
- C. Construct Star Plots (using percent parameter sensitivities) from slide 60 for NDB bits
- D. Construct Star Plots (using percent parameter sensitivities) combine the results from slide 61 and 63 for NDB bits into one plot

The PPT

Prepare a 16 ppt PowerPoint presentation. Slide one title and your name (1), Outline (2), Objective (3), Drag Bits General Information (4), Technical Approach (5), Present procedure for Start Plot creation (6) and present and discuss results from A. (Slide 7, 8 and 9), Present and discuss results from B. above (10), Summary and Conclusions for PDCs (11) Presents and discuss results from C. above (12), Explain what NDB pump-off and include the parameters that affects the pump-off (13) Presents and discuss results from D. above (14), Summary and Conclusions for NDBs(15), Presents your learnings from the exercise (16).



Assignment due October 10!