DIAMOND BIT MATHEMATICAL MODEL

The mathematical model of a diamond drill bit represents the actual behavior of the bit as it penetrates the formation. Two mechanical factors influence the diamond tools performance. They are (1) the number of effective cutting elements and the number of times any cutting elements passes over the formation, and (2) the amount of surface area in contact with the formation thus controlling the unit loading of the cutting element.

The Number of Effective Blades

One effective blade can be defined as a cutting element which covers the entire bottom of the hole one time during one complete revolution of the drill string.

Therefore, by simply adding the width of cut (C) made by each diamond, we can calculate the number of diamonds it will take to form one blade. The width of cut (C), called the diamond's "coverage", increases as the diamond penetrates into the rock. Values for "C" for various diamond sizes and penetration depths are shown in Table A. The penetration (P) is measured in thousandths of an inch. The "E.B.", or effective blade line, on the mathematical model represents the number of blades at any given "P" value and is obtained by dividing the total diamond coverage on the bit by the total length of a single blade (TBL) measured across the face of the bit. The penetration (P) times the number of effective

this Handbook. Next calculate two values for "E.B." and then the corresponding values for penetration rate at the selected "P" values using rotary speed conditions that the bit was actually turned.

Determine the "A.T." and then the formation resistance values at the selected "P" values for actual bit weight.

The drilling rate curve is created on the graph worksheet by plotting the calculated penetration rates (on the right side of the graph) versus the selected "P" values (across the bottom of the graph) and drawing a straight line through the two points. Label this line "Drilling Rate @__________ RPM."

The formation resistance curve is created by plotting calculated formation resistance (on the left side of the graph) versus the selected "P" values and drawing a straight line through the two points. Label this line "Formation Resistance @ ______________ lbs."

A similar set of calculations and graph are prepared for the bit and operating conditions to be evaluated. It is now possible to make an estimate of anticipated performance.

Enter the reference graph at the actual experience penetration rate (right side of graph) and draw a line horizontally to intersect the "Drilling Rate" curve. Then proceed vertically to the "Formation Resistance" curve. By drawing a horizontal line to the left side of the graph, the effective formation resistance can be determined.

EFFECTIVE BLADES:

P INCHES	C INCHES FROM TABLE A	×	NO. FACE STONES	=		÷	TBL FROM TABLE C	=	E.B.
.0025	.0328	×	1271	=	41.69	÷	5.975	=	6.97
.0010	.0209	×	1271	=	26.56	÷	5.975	=	4.44

DRILLING RATE:

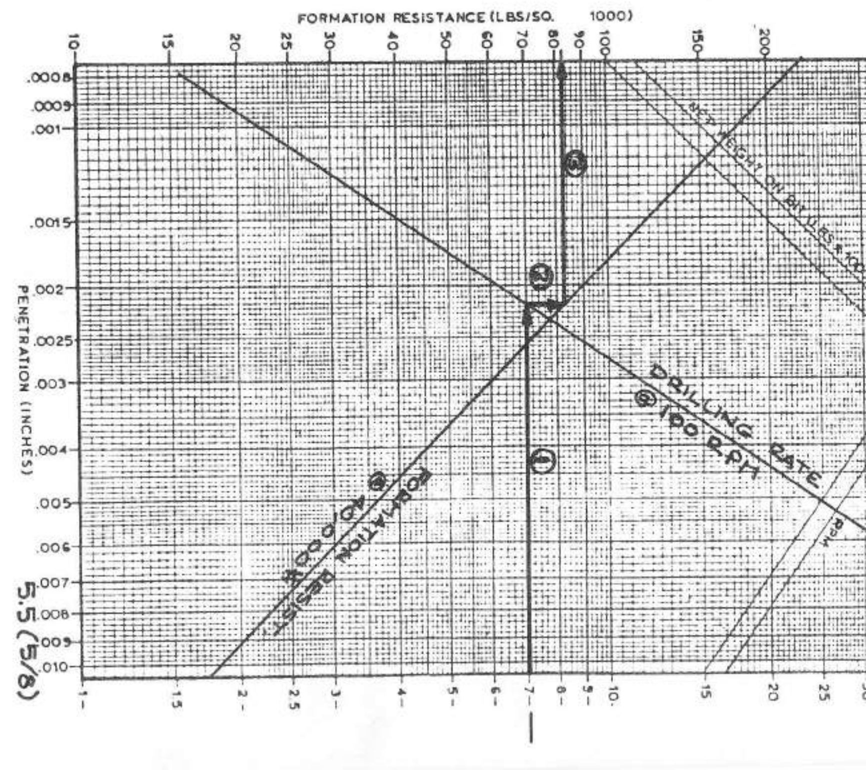
P INCHES	×	E.B.	×	RPM	×	5	=	PEN. RATE FT/HR
.0025	×	6.97	×	100	×	5	=	8.7
.0010	×	4.44	×	100	×	5	=	2.2

TOTAL DIAMOND AREA:

P INCHES	A SQ. INCHES FROM TABLE B	×	NO. FACE STONES	÷	2	=	A.T. SQ. INCHES
.0025	.00086	×	1271	÷	2	=	.547
.0010	.00035	×	1271	÷	2	=	.222

FORMATION RESISTANCE:

P INCHES	NET BIT WEIGHT LBS.	÷	A.T. SQ. INCHES	=	FORMATION RESISTANCE LBS/SQ INCH
.0025	40,000	÷	.547	=	73,126
.0010	40,000	÷	.222	=	180,180



blades (E.B.) times the number of revolutions will give us the resulting penetration rate.

Diamond Area and the Formation Resistance

From Table B we can read the actual area (A) of each diamond in contact with the rock at any "p" value. By multiplying the number of face stones (NFS) by the diamond area (A), we can calculate the total area (A.T.) in contact with the rock.

The formation resistance can be calculated by dividing the net bit weight by the total area (A.T.).

By starting with the known penetration rate of a diamond bit in a specific formation, it is possible to estimate the penetration rate of a different bit design and/or the influence of changing rotary speed and/or net bit weight, so long as bit size, mud weight, and depth are essentially the same. A set of worksheets have been developed to simplify the evaluation procedure.

Using the Worksheets

First start with the bit for which the penetration rate is known. Obtain values for "C" from Table A and "A" from Table B. Total blade length (TBL) is found in Table C under the proper crown shape and cone angle column. The number of face stones and diamond size can be found from the tables in the Styles section of

Now the procedure is reversed, using the new bit graph. Enter the graph at the effective formation resistance value (just determined on the reference graph) on the left and proceed horizontally to the "Formation Resistance" curve, then vertically to the "Drilling Rate" curve and finally horizontally to the right to obtain predicted penetration rate for the new operating conditions.

By preparing several "Formation Resistance" curves at different net bit weights and several "Drilling Rate" curves at different rotary speeds, the influence of these parameters on penetration rate can be studied.

EFFECTIVE BLADES:

P INCHES	C INCHES FROM TABLE A	×	NO. FACE STONES	=		÷	TBL FROM TABLE C	=	E.B.
.0025	.0371	×	934	=	34.65	÷	5.850	=	5.92
.0010	.0236	×	934	=	22.04	÷	5.850	=	3.77

DRILLING RATE:

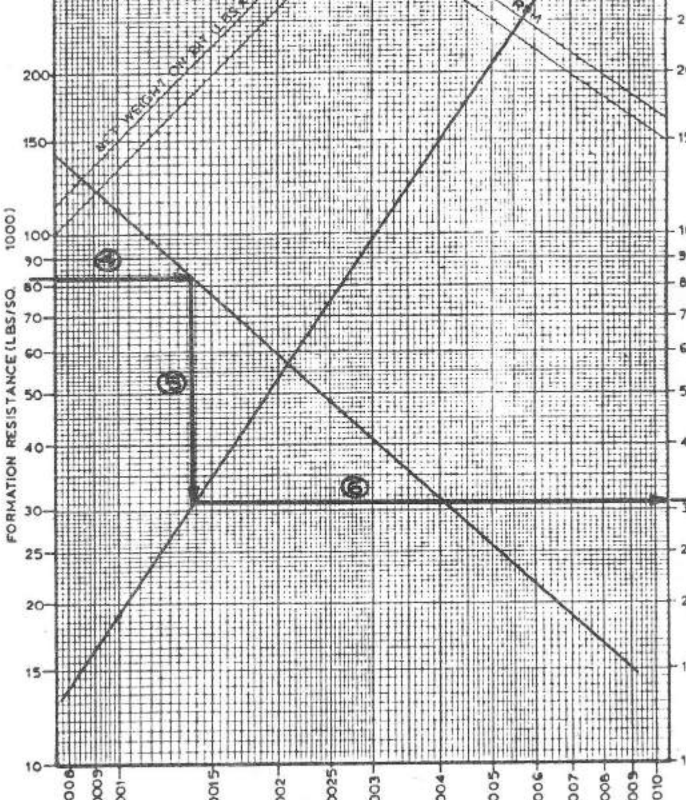
P INCHES	×	E.B.	×	RPM	×	5	=	PEN. RATE FT/HR
.0025	×	5.92	×	100	×	5	=	7.4
.0010	×	3.77	×	100	×	5	=	1.9

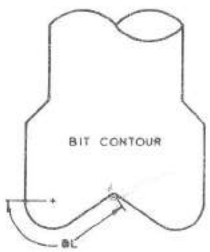
TOTAL DIAMOND AREA:

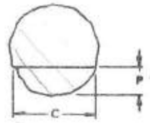
P INCHES	A SQ. INCHES FROM TABLE B	×	NO. FACE STONES	÷	2	=	A.T. SQ. INCHES
.0025	.00109	×	934	÷	2	=	.509
.0010	.00044	×	934	÷	2	-	.205

FORMATION RESISTANCE:

P INCHES	NET BIT WEIGHT LBS.	÷	A.T. SQ. INCHES	=	FORMATION RESISTANCE LBS/SQ INCH
.0025	25,000	÷	.509	=	49,116
.0010	25,000	÷	.205	=	121,951







$A = \frac{\text{SURFACE AREA OF SPHERICAL SEGMENT}}{2}$

WHERE:

- P: PENETRATION OF DIAMOND INTO ROCK OR DEPTH OF GROOVE CUT BY DIAMOND
- C: COVERAGE-WIDTH OF GROOVE CUT BY EACH STONE @ P
- C_T: TOTAL COVERAGE OF ALL DIAMONDS ON CUTTING FACE OF BIT @ P (C_T = C x NO. OF STONES)
- A: AREA OF DIAMOND IN CONTACT WITH ROCK @ P
- A_T: TOTAL AREA OF DIAMONDS IN CONTACT WITH ROCK (A_T = A x NO. OF STONES)
- BL: BLADE LENGTH
- BN: NO. OF EFFECTIVE BLADES @ P

TABLE A
"C" VALUES

ROUND STONES

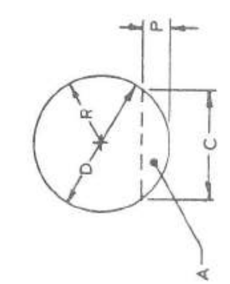
STONES PER CT.	DIAMETER	CARAT WEIGHT	PENETRATION (P)			
			.010	.005	.0025	.0010
32	.060	.0314	.04472	.0332	.0240	.0153
20	.070	.0499	.0490	.0361	.0260	.0166
13	.080	.0746	.0529	.0387	.0278	.0178
10	.090	.1062	.0566	.0412	.0296	.0189
7	.100	.1458	.0600	.0436	.0312	.0199
5	.110	.1939	.0632	.0458	.0328	.0209
4	.120	.2519	.0663	.0480	.0343	.0218
3	.130	.3203	.0693	.0500	.0357	.0227
2.5	.140	.4000	.0721	.0520	.0371	.0236
2	.150	.4920	.0748	.0538	.0384	.0244
1.7	.160	.5970	.0775	.0556	.0397	.0252
1.4	.170	.7160	.0800	.0574	.0409	.0260
1.2	.180	.8503	.0825	.0592	.0421	.0268
1	.190	1.000	.0849	.0608	.0433	.0275

TABLE B
"A" VALUES

ROUND STONES

STONES PER CT.	DIAMETER	CARAT WEIGHT	PENETRATION (P)			
			.010	.005	.0025	.0010
32	.060	.0314	.001885	.00094	.00047	.00019
20	.070	.0499	.002200	.00110	.00055	.00022
13	.080	.0746	.002514	.00126	.00063	.00025
10	.090	.1062	.002828	.00141	.00071	.00028
7	.100	.1458	.003142	.00157	.00079	.00031
5	.110	.1939	.003456	.00173	.00086	.00035
4	.120	.2519	.003770	.00188	.00094	.00038
3	.130	.3203	.004084	.00204	.00102	.00041
2.5	.140	.4000	.004399	.00220	.00109	.00044
2	.150	.4920	.004713	.00235	.00118	.00047
1.7	.160	.5970	.005027	.00251	.00126	.00050
1.4	.170	.7160	.005341	.00267	.00134	.00053
1.2	.180	.8503	.005655	.00282	.00141	.00057
1	.190	1.000	.005969	.00298	.00149	.00060

DIAMETER	CARAT WEIGHT	PENETRATION (P)			
		.010	.005	.0025	.0010
.200	1.166	.006284	.00314	.00157	.00063
.210	1.350	.006598	.00329	.00165	.00066
.220	1.552	.006912	.00345	.00173	.00069
.230	1.773	.007226	.00361	.00181	.00072
.240	2.015	.00754	.00377	.00188	.00075
.250	2.278	.007854	.00392	.00196	.00079
.260	2.562	.008169	.00408	.00204	.00082
.270	2.869	.008483	.00424	.00212	.00085
.280	3.200	.008797	.00439	.00220	.00088
.290	3.556	.009111	.00455	.00228	.00091
.300	3.936	.009425	.00471	.00236	.00094
.310	4.343	.009739	.00487	.00243	.00097
.320	4.777	.010054	.00503	.00251	.00100
.330	5.239	.010368	.00518	.00259	.00104
.340	5.730	.010682	.00534	.00267	.00107
.350	6.250	.010996	.00550	.00275	.00110



D = DIAMETER
R = RADIUS OF ROUNDED CONDITIONED DIAMONDS
P = DIAMOND PENETRATION
C = COVERAGE IN INCHES
CARAT WEIGHT = $1166.46R^3$
C = $2\sqrt{P(2R-P)}$ OR $2\sqrt{P(D-P)}$
A = $2\pi RP$ OR $6.2832RP$
V = $\pi P^2(R-\frac{P}{3}) = \pi P(\frac{C^2}{8}+\frac{P^2}{6})$

TO CALCULATE DIAMOND SPACING WHERE DIAMONDS ARE SET IN A HELIX

DIAMOND SPACING = $\frac{C @ P \times \text{NO. OF ROWS}}{\text{NO. OF BLADES DESIRED}}$

TABLE A (CONTINUED)
"C" VALUES — ROUND STONES

DIAMETER	CARAT WEIGHT	PENETRATION (P)			
		.010	.005	.0025	.0010
.200	1.166	.08718	.0624	.0444	.0282
.210	1.350	.08944	.0640	.0456	.0289
.220	1.552	.09165	.0655	.0466	.0296
.230	1.773	.09381	.0671	.0477	.0303
.240	2.015	.09591	.0685	.0487	.0309
.250	2.278	.09798	.0700	.0497	.0316
.260	2.562	.10000	.0714	.0507	.0322
.270	2.869	.10198	.0728	.0517	.0328
.280	3.200	.1039	.0742	.0526	.0334
.290	3.556	.10583	.0755	.0536	.0340
.300	3.936	.1077	.0768	.0545	.0346
.310	4.343	.10954	.0781	.0555	.0352
.320	4.777	.11135	.0794	.0563	.0357
.330	5.239	.11313	.0806	.0572	.0363
.340	5.730	.11489	.0819	.0581	.0368
.350	6.250	.11662	.0831	.0589	.0374

TABLE C

TOTAL BLADE LENGTH (TBL)

R CROWN				
Bit Size	60° Cone	90° Cone	110° Cone	120° Cone
4 1/2	3.530	3.139	2.957	2.898
4 5/8	3.617	3.226	3.044	2.987
4 3/4	3.706	3.311	3.128	3.075
5 3/4	4.518	4.009	3.792	3.727
5 7/8	4.607	4.094	3.879	3.815
6	4.693	3.181	3.966	3.901
6 1/8	4.782	4.266	4.053	3.989
6 1/2	5.100	4.532	4.275	4.206
6 5/8	5.189	4.619	4.362	4.294
6 3/4	5.276	4.707	4.454	4.380
7 1/2	5.886	5.232	4.934	4.844
7 5/8	5.973	5.316	5.021	4.292
7 3/4	6.062	5.404	5.084	5.017
8 3/8	6.569	5.845	5.497	5.394
8 1/2	6.658	5.930	5.585	5.480
8 5/8	6.745	6.017	5.672	5.568
8 3/4	6.834	6.102	5.757	5.656
9 1/2	7.452	6.629	6.237	6.095
9 5/8	7.541	6.713	6.324	6.182
9 3/4	7.627	6.801	6.411	6.268
9 7/8	7.716	6.888	6.496	6.356
10 1/2	8.234	7.321	6.911	6.761
10 5/8	8.320	7.409	6.998	6.849
10 3/4	8.409	7.496	7.083	6.935
12	9.435	8.366	7.909	7.743
12 3/16	9.566	8.495	8.040	7.743
12 1/4	9.611.	8.538	8.083	7.919
13 3/4				9.299

TABLE C

TOTAL BLADE LENGTH (TBL)

	C Crown			V Crown	
BIT SIZE	90° Cone	100° Cone	110° Cone	90° Cone	110° Cone
4 1/2	3.446	3.355	3.285	3.607	3.462
4 5/8	3.571	3.480	3.410	3.732	3.587
4 3/4	3.696	3.605	3.535	3.857	3.712
5 3/4	4.247	4.141	4.059	4.475	4.281
5 7/8	4.372	4.266	4.184	4.600	4.406
6	4.497	4.391	4.309	4.725	4.531
6 1/8	4.622	4.516	4.434	4.850	4.656
6 1/2	4.743	4.620	4.525	5.096	4.886
6 5/8	4.863	4.745	4.650	5.221	5.011
6 3/4	4.993	4.870	4.775	5.346	5.136
7 1/2	5.471	5.319	5.202	5.842	5.599
7 5/8	5.596	5.444	5.327	5.967	5.724
7 3/4	5.721	5.569	5.452	6.092	5.849
8 3/8	6.028	5.850	5.710	6.462	6.186
8 1/2	6.153	5.975	5.835	6.587	6.311
8 5/8	6.278	6.100	5.960	6.712	6.436
8 3/4	6.403	6.225	6.085	6.837	6.561
9 1/2	6.790	6.580	6.419	7.299	6.987
9 5/8	6.915	6.705	6.544	7.424	7.112
9 3/4	7.040	6.830	6.669	7.549	7.237
9 7/8	7.165	6.955	6.794	7.674	7.362
10 1/2	7.440	7.215	7.040	8.044	7.700
10 5/8	7.565	7.340	7.165	8.169	7.825
10 3/4	7.690	7.465	7.290	8.294	7.950
12	8.402	8.159	7.973	9.144	8.750
12 3/16	8.590	8.347	8.161	9.332	8.938
12 1/4	8.652	8.409	8.223	9.394	9.000
17 1/2		12.406			