

Fortezza da Basso • FLORENCE (Italy)

30th September • 2nd October 2019

The role of torque in the reaming process in HDD applications

Renzo Chirulli*

Applications Specialist Pipeline

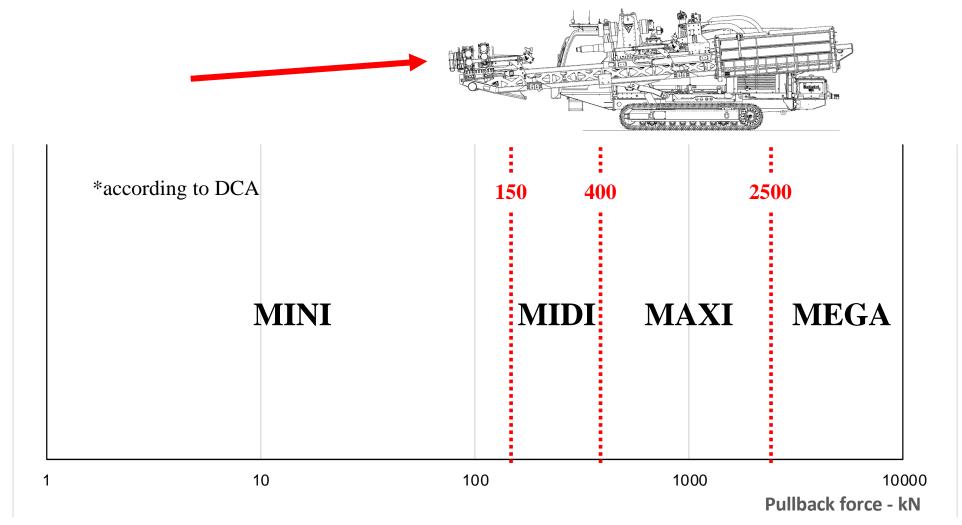
René Albert*

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Rig classification*

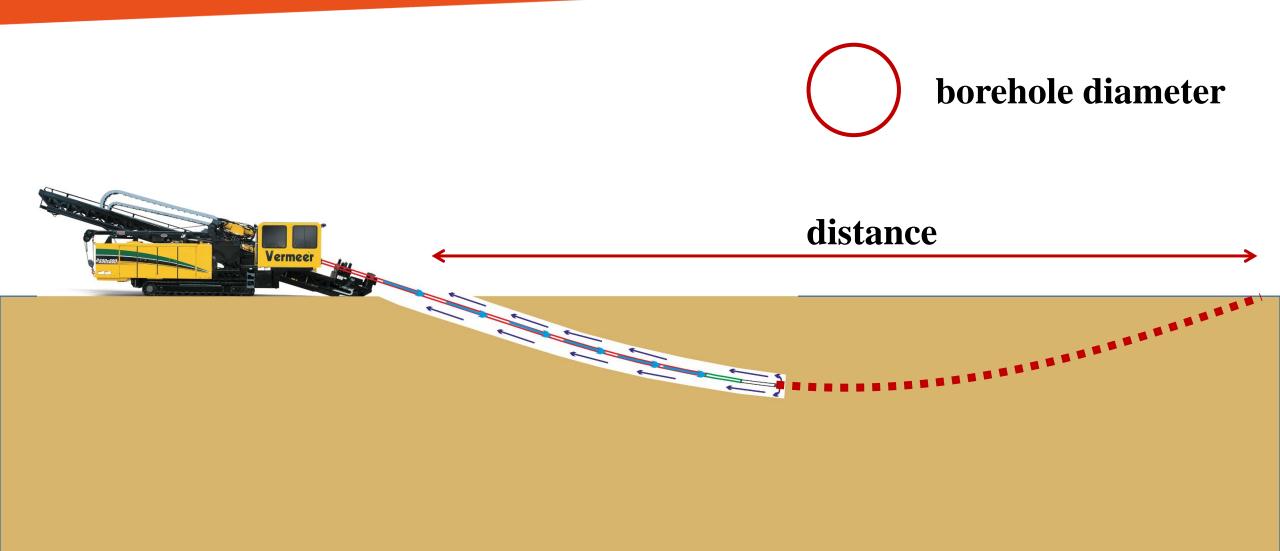




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What the pullback force tells us about the hole-making capability of a drill rig?







Stiffness of drill pipes

Size of drill pipe

Buckling causes:

- Problems on directional control
- Ineffective axial load transfer to the bit
- Drill pipe failure





Make-up Torque

Drill Pipe and Tool Joint Data - Range 4-1/2" - 7-5/8"

Normal size Normal wight Grade Upset Thickness D Strength In In Hols Ibs Ibs In In Hols Ibs Ibs In In Hols Ibs	Pipe body										Tool Joint								
4-1/2 16.60 S-135 EU 0.337 3.826 55.500 595.000 NC46 6-114 2.3/4 9 12 120 26.600 44.400 1.1	Nominal size		inal size	Nominal weight	Grade	Upset		ID			Connection	OD	ID	Tong	_ength	Material Yield			Tensile Strength
4-1/2 16.60			in	ft-lbs			in	in	ft-lbs	lbs		in	in	Pin in	Box in	Strength KSI	ft-lbs	ft-lbs	lbs
4-1/2		4-1/2	4-1/2	16.60			0.337		55,500	595,000	NC46	6-114	2-3/4	9	12	120	26,600	44,400	1,180,000
4-1/2 16.60 S-135 EU 0.337 3.826. 55.500 595.000 NC50 DS 6-3/8 3-1/4 9 12 130 47.900 79.800 1.3 4.1/2 20.00 S-135 EU 0.430 3.640. 66.400 742.000 NC50 DS 6-3/8 3-1/4 9 12 120 26.600 44.400 1.1 4.1/2 20.00 S-135 EU 0.430 3.640. 66.400 742.000 NC50 DS 6-3/8 3-1/4 9 12 120 34.500 57.500 1.4 4.1/2 20.00 S-135 EU 0.430 3.640. 66.400 742.000 NC50 DS 6-3/8 3-1/4 9 12 130 47.900 79.800 1.3 4.1/2 20.00 S-135 EU 0.362 4.276. 74.100 712.000 T.12.000 T.12.00			-				0.337			595,000	NC46 DS						29,200	48,600	976,000
4-1/2 20.00			_							,							-		1,110,000
4-1/2 20.00			4-1/2	16.60	S-135	EU	0.337	3.826.	55,500	595,000	NC50 DS	6-3/8	3-1/4	9	12	130	47,900	79,800	1,380,000
A-1/2 20.00 S-135 EU 0.430 3.640 66,400 742,000 NC50 DS 6-3/8 3-1/4 9 12 130 47,900 79,800 1,3			4-1/2	20.00			0.430	3.640.	66,400	742,000	NC46		2-3/4			120	26,600	44,400	1,180,000
5 19.50 S-135 EU 0.362 4.276. 74,100 712,000 51/2 FH 0.34 10 12 120 43,300 72,200 1,6 5 19.50 S-135 EU 0.362 4.276. 74,100 712,000 S-1/2 FH DS 7 3.3/4 10 12 130 58,400 97,300 1,5 5 19.50 S-135 EU 0.362 4.276. 74,100 712,000 NC50 6-5/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-5/8 [3-1/2] 9 12 130 40,600 67,700 1,2 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.500 4.000 94,100 954,000 NC50 S-6/8 [2-3/4] 9 12 120 38,000 63,400 1,5 5 12 5.60 S-135 EU 0.361 5.153. 105,000 844,000 S-1/2 FH DS 7 4 10 12 120 33,400 S-5,700 1,2 5.7/8 23.40 S-135 EU 0.361 5.153. 105,000 844,000 S-1/2 FH DS 7 4 10 12 120 33,400 S-5,700 1,2 5.7/8 26.30 S-135 EU 0.415 5.045. 118,000 961,000 S-1/2 FH DS 7 4 10 12 120 33,400 S-5,700 1,2 5.7/8 26.30 S-135 EU 0.415 5.045. 118,000 961,000 S-1/2 FH DS 7 -1/8 4 10 12 130 49,400 82,400 1,3 5.7/8 5.7/8 25.20 S-135 EU 0.362 5.901. 137,000 962,000 S-1/2 FH DS 7 -1/8 4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH DS 7 -7/8 4-3/4 10 13 130 74,100 123,000 1,8 5.7/8 5.7/8 33.7 S-135 EU 0.430 6.656. 214,900 1,312,100 65/8 FH DS 7 -7/8 4-3/4 10 13 130 74,100 123,000 1,8 5.7/8 5.7/8 33.7 S-135 EU 0.430 6.656. 214,900 1,312,100 65/8 FH DS 7 -7/8 4-3/4 10 13 130 74,100 123,000 1,8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 33.7 S-135 EU 0.430 6.656. 214,900 1,312,100 65/8 FH DS 7 -7/8 4-3/4 10 13 130 102,420 170,700 2,2 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7/8 5.7									,	,									1,420,000
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5 19.50 8-135 EU 0.362 4.276. 74,100 712,000 NC50 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 19.50 S-135 EU 0.362 4.276. 74,100 712,000 NC50 DS 6-5/8 3-1/2 9 12 130 40,600 67,700 1,2 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 S-1/2 FH 7-1/4 3-1/4 10 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 NC50 DS 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 9 12 120 38,000 63,400 1,5 1/2 FH DS 7-7/8 2-3/4 10 12 120 33,400 55,700 1,2 1/2 1/2 1/2 1/2 1/2 1/2 1/2 1/2 1/2 1/		5	5	19.50	S-135	IEU	0.362	4.276.	74,100	712,000	5 1/2 FH	7-1/4	3-1/2	10	12	120	43,300	72,200	1,620,000
5 19.50 S-135 EU 0.362 4.276 74,100 712,000 NC50 DS 6-5/8 3-1/2 9 12 130 40,600 67,700 1,2 5 25.60 S-135 EU 0.500 4.000 94,100 954,000 NC50 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000 94,100 954,000 NC50 DS 6-1/2 3-1/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000 94,100 954,000 NC50 DS 6-1/2 3-1/4 9 12 130 48,300 80,600 1,3 5 -7/8 23.40 S-135 EU 0.361 5.153 105,000 844,000 51/2 FH 7 4 10 12 120 33,400 55,700 1,2 5 -7/8 23.40 S-135 EU 0.361 5.153 105,000 844,000 51/2 FH S 7 4 10 12 130 49,400 82,400 1,3 5 -7/8 26.30 S-135 EU 0.415 5.045 118,000 961,000 51/2 FH S 7 1/8 4 10 12 130 49,400 82,400 1,3 5 -7/8 26.30 S-135 EU 0.415 5.045 118,000 961,000 51/2 FH DS 7 1/8 4 10 12 130 49,400 82,400 1,3 6 -5/8 25.20 S-135 EU 0.330 5.965 127,000 881,000 65/8 FH S -1/2 4-1/4 10 13 120 65,000 108,000 2,1 6 -5/8 27.70 S-135 EU 0.362 5.901 137,000 962,000 65/8 FH S -1/2 4-1/4 10 13 130 74,100 123,000 1,8 7 -5/8 33.7 S-135 EU 0.430 6.765 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2 7 -5/8 33.7 S-135 EU 0.430 6.765 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2 8 -7-5/8 33.7 S-135 EU 0.430 6.765 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2 8 -7-5/8 33.7 S-135 EU 0.430 6.765 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2 8 -7-5/8 33.7 S-135 EU 0.430 6.765 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2 8 -7-5/8 33.7 S-135 EU 0.430 6.76			5	19.50	S-135	IEU	0.362	4.276.	74,100	712,000	5 1/2 FH DS			10	12	130	58,400	97,300	1,570,000
5 25.60 S-135 IEU 0.500 4.000. 94,100 954,000			5	19.50	8-135	IEU	0.362	4.276.	74,100	712,000	NC50			9	12	120	38,000	63,400	1,550,000
5 25.60 8-135 EU 0.500 4.000. 94,100 954,000 NC50 6-5/8 2-3/4 9 12 120 38,000 63,400 1,5 5 25.60 S-135 EU 0.500 4.000. 94,100 954,000 NC50 DS 6-1/2 3-1/4 9 12 130 48,300 80,600 1,3 5-7/8 23.40 S-135 EU 0.361 5.153. 105,000 844,000 51/2 FH 7 4 10 12 120 33,400 55,700 1,2 5-7/8 26.30 S-135 EU 0.361 5.153. 105,000 844,000 51/2 FH 7 -118 4 10 12 130 49,400 82,400 1,3 5-7/8 26.30 S-135 EU 0.415 5.045. 118,000 961,000 51/2 FH 7-118 4 10 12 130 49,400 82,400 1,3 5-7/8 26.30 S-135 EU 0.415 5.045. 118,000 961,000 51/2 FH 7-118 4 10 12 130 49,400 82,400 1,3 6-5/8 25.20 8-135 EU 0.330 5.965. 127,000 881,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 6-5/8 27.70 S-135 EU 0.362 5.901. 137,000 962,000 65/8 FH BS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 6-5/8 EU 0.440 EU 0.44			5	19.50	S-135	IEU	0.362	4.276.	74,100	712,000	NC50 DS	6-5/8	3-1/2	9	12	130	40,600	67,700	1,200,000
5 25.60 S-135 IEU 0.500 4.000. 94,100 954,000 NC50 DS 6-1/2 3-1/4 9 12 130 48,300 80,600 1,3 5-7/8 23.40 S-135 IEU 0.361 5.153. 105,000 844,000 51/2 FH 7 4 10 12 120 33,400 55,700 1,2 5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 51/2 FH 7-118 4 10 12 120 33,400 82,400 1,3 5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 51/2 FH 7-118 4 10 12 120 33,400 82,400 1,3 5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 51/2 FH DS 7-1/8 4 10 12 130 49,400 82,400 1,3 6-5/8 25.20 8-135 IEU 0.330 5.965. 127,000 881,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 65/8 FH 8-1/2 4-1/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8			5	25.60	S-135	IEU	0.500	4.000.	94,100	954,000	5 1/2 FH			10	12	120	47,200	78,700	1,780,000
5-7/8			5	25.60	8-135	IEU	0.500	4.000.	94,100	954,000	NC50			9	12	120	38,000	63,400	1,550,000
5-7/8			5	25.60	S-135	IEU	0.500	4.000.	94,100	954,000	NC50 DS	6-1/2	3-1/4	9	12	130	48,300	80,600	1,380,000
5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 5 1/2 FH DS 7-1/8 4 10 12 130 49,400 82,400 1,3 6-5/8 25.20 8-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 25.20 S-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH DS 7-7/8 5 10 13 130 64,700 108,000 1,5 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH B 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2		2-7/8	5-7/8	23.40	S-135	IEU	0.361	5.153.	105,000	844,000	5 1/2 FH	7	4	10	12	120	33,400	55,700	1,270,000
5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 5 1/2 FH DS 7-1/8 4 10 12 130 49,400 82,400 1,3 6-5/8 25.20 8-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 25.20 S-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH DS 7-7/8 5 10 13 130 64,700 108,000 1,5 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH B 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2			5-7/8	23.40	S-135	IEU	0.361	5.153.	105,000	844,000	5 1/2 FH DS	7	4	10	12	130	49,400	82,400	1,370,000
5-7/8 26.30 S-135 IEU 0.415 5.045. 118,000 961,000 5 1/2 FH DS 7-1/8 4 10 12 130 49,400 82,400 1,3 6-5/8 25.20 8-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 25.20 S-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH DS 7-7/8 5 10 13 130 64,700 108,000 1,5 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH B 8-1/2 4-1/4 10 13 120 65,000 108,000 2,1 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2			5-7/8	26.30	S-135	IEU	0.415	5.045.	118,000	961,000	5 1/2 FH	7-118	4	10	12	120	33,400	55,700	1,270,000
6-5/8 25.20 S-135 IEU 0.330 5.965. 127,000 881,000 65/8 FH DS 7-7/8 5 10 13 130 64,700 108,000 1,5 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 65/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 65/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2						IEU						7-1/8	4	10	12	130			1,370,000
6-5/8 25.20 S-135 IEU 0.330 5.965. 127,000 881,000 6 5/8 FH DS 7-7/8 5 10 13 130 64,700 108,000 1,5 6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8 7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2		6-5/8	6-5/8	25.20	8-135	IEU	0.330	5.965.	127,000	881,000	6 5/8 FH	8-1/2	4-1/4	10	13	120	65,000	108,000	2,100,000
6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8			_	25.20	S-135	IEU	0.330				6 5/8 FH DS			10	13	130	64,700	108,000	1,570,000
6-5/8 27.70 S-135 IEU 0.362 5.901. 137,000 962,000 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 74,100 123,000 1,8			6-5/8	27.70	S-135	IEU	0.362	5.901.	137.000	962.000	6 5/8 FH	8-1/2	4-1/4	10	13	120	65.000	108.000	2,100,000
7-5/8 33.7 S-135 IEU 0.430 6.765. 214,900 1,312,100 6 5/8 FH DS 7-7/8 4-3/4 10 13 130 102,420 170,700 2,2				-					- ,					10	_				1,820,000
		7 5/8	7-5/8	33.7	S-135	IEU	0.430	6.765.	214,900	1,312,100	6 5/8 FH DS			10	13	130	102,420	170,700	2,278,000

Mechanical Specific Energy - MSE

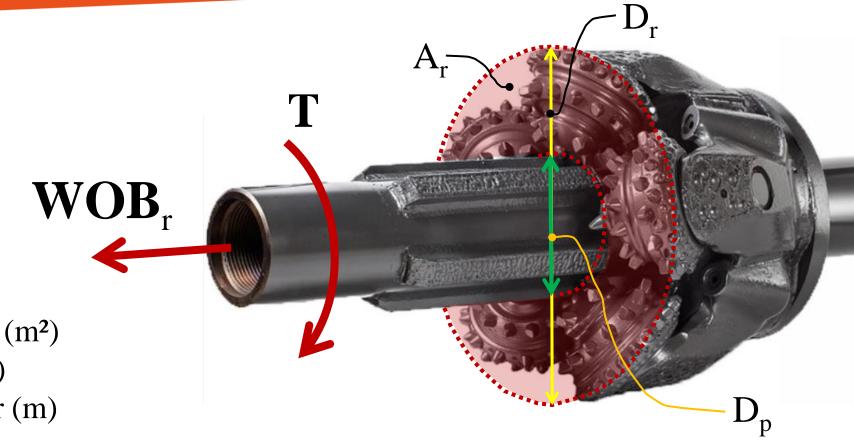


Mechanical Specific Energy (MSE), first introduced by R. Teale in 1965 is the amount of energy that has to be added to a unit volume of soil to excavate it (*Miedema*, 2016).

MSE is measured in J/m³ (Nm/m³)

Basic parameter in the reaming process





 A_r = crown cross section (m²)

 D_r = reamer diameter (m)

 D_p = pre-reamer diameter (m)

T = torque (Nm)

WOB _r = pullback force - or Weight On Bit (N)

ROP = rate of penetration (m/s)

Basic parameter in the reaming process



 $Q_s = A_r \cdot ROP$ volume of soil drilled per unit time Q_s (m³/s).

The product $MSE \cdot Q_s$ (Nm/s = W) is then the mechanical power needed to drill under such operational parameters:

$$\frac{MSE \cdot Q_s}{E_r} = T\omega + WOB_r \cdot ROP = P_r + P_t$$

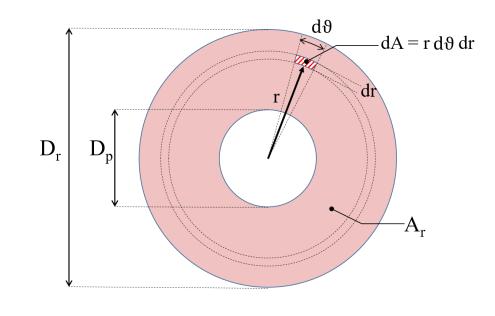
- $P_r = T\omega$ is the power required to rotate the reamer,
- $P_t = WOB_r \cdot ROP$ is the power required to translate it along the borehole.
- $E_r < 1$ is the mechanical efficiency of the reamer

Torque



$$A_r = \frac{(D_r^2 - D_p^2)}{4} \pi \qquad T = \frac{WOB_r \cdot \mu_r (D_r^3 - D_p^3)}{3 (D_r^2 - D_p^2)}$$

 μ_r indicates the reamer's specific **coefficient of sliding** friction [0.3 ÷ 0.85].



Because
$$D_p = k \cdot D_r$$
 where $0 \le k \le 1$

$$T = \frac{WOB_r \cdot \mu_r \cdot D_r}{k_r}$$

$$k_r = \frac{3(1-k^2)}{1-k^3} = \frac{3(k+1)}{(k^2+k+1)}$$

$$3 \ge k_r \ge 2$$
 for $0 \le k \le 1$

Example: TCI roller cones hole opener



For hole openers equipped with TCI roller cones:

$$\mu_r = 0.3$$

 k_r ranges between 2.2 and 2.3



Example: TCI roller cones hole opener



Example:

$$D_r = 42$$
" = 1.067 m
 $D_p = 32$ " = 0.813 m

5 roller cones, maximum load per cutter $WOB_c = 8 \text{ t } (78480 \text{ N}).$

$$WOB_r = 5 \cdot 78480 = 392400 \ N = 40 \ t$$

$$T = \frac{WOB_r \cdot \mu_r}{3} \frac{\left(D_r^3 - D_p^3\right)}{\left(D_r^2 - D_p^2\right)} = 55653.4 \ Nm$$



Example: TCI roller cones hole opener



Example:

- Rotational speed is equal to 30 rpm ($\omega = 3.14 \text{ rad/s}$)
- Pullback speed is $s_p = 0.0022$ m/s (8 m/h),

$$Q_s = ROP \cdot A_r = 8.33 \cdot 10^{-4} \text{ m}^3/\text{s}$$

the power P needed at the reamer is given by:

$$P = T\omega + WOB_r \cdot ROP = P_r + P_t = 174.84 \, kW + 0.872 \, kW$$

$$r_P = \frac{P_t}{P_r} 100\% = 0.5\%$$



Conclusions



The pullback force itself provides limited information about the borehole-making capability of an HDD rig, because quite the whole energy spent, during the reaming process, is needed to rotate the reamer against the soil under a certain value of the pullback force.

The ratio between the energy spent to pull back the reamer and the energy spent to rotate it while reaming the borehole can be in many cases very close to zero.

Based on this consideration, the way the HDD rigs are currently classified should reflect the borehole-making capability of the rigs (that is mostly related to the torque capability of the machine) instead of the mere pullback force.



Conclusions



Thank you!

