37TH INTERNATIONAL NO-DIG FLORENCE 2019

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The role of torque in the reaming process in HDD applications

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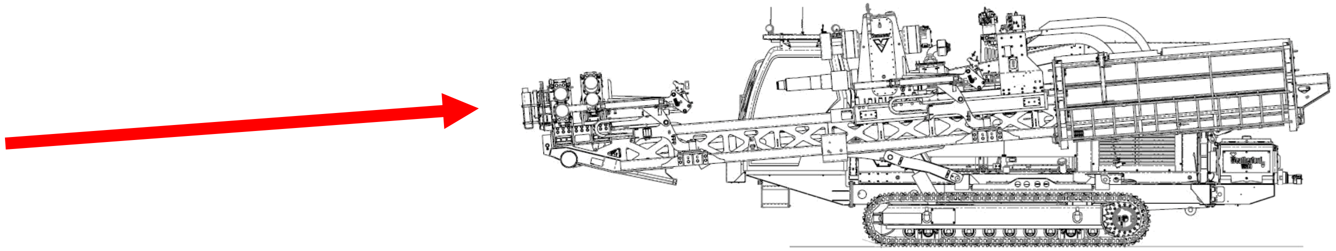
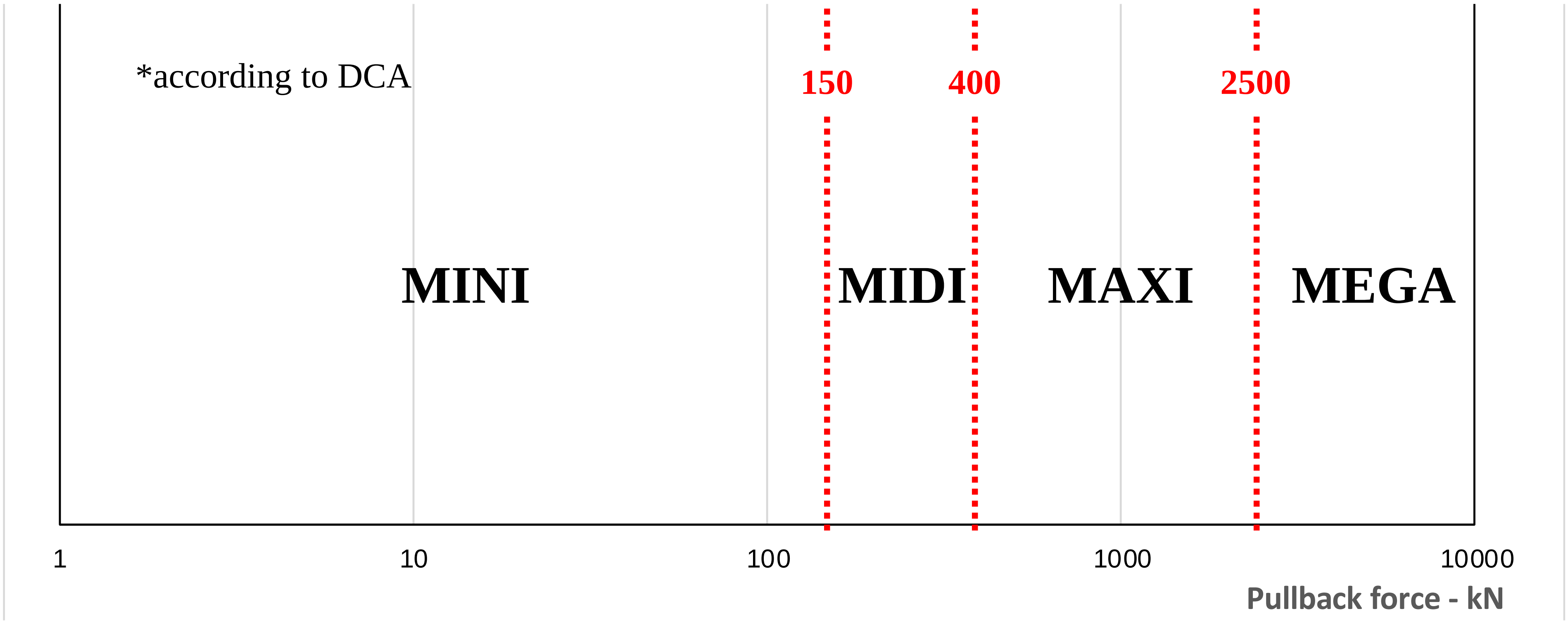
Rig classification*





*according to DCA

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

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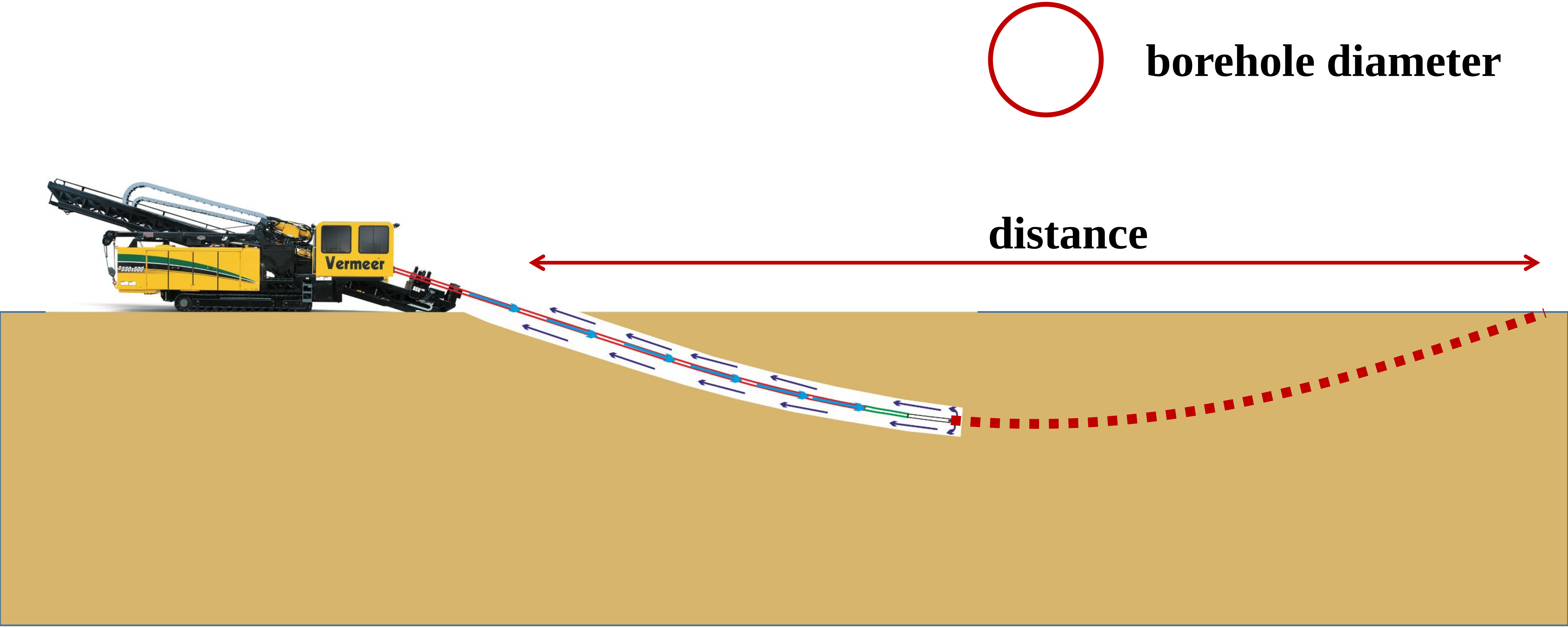


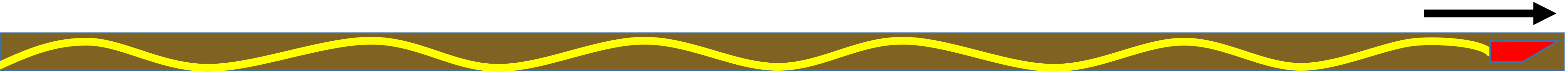
Distance

Stiffness of drill pipes

Size of drill pipe

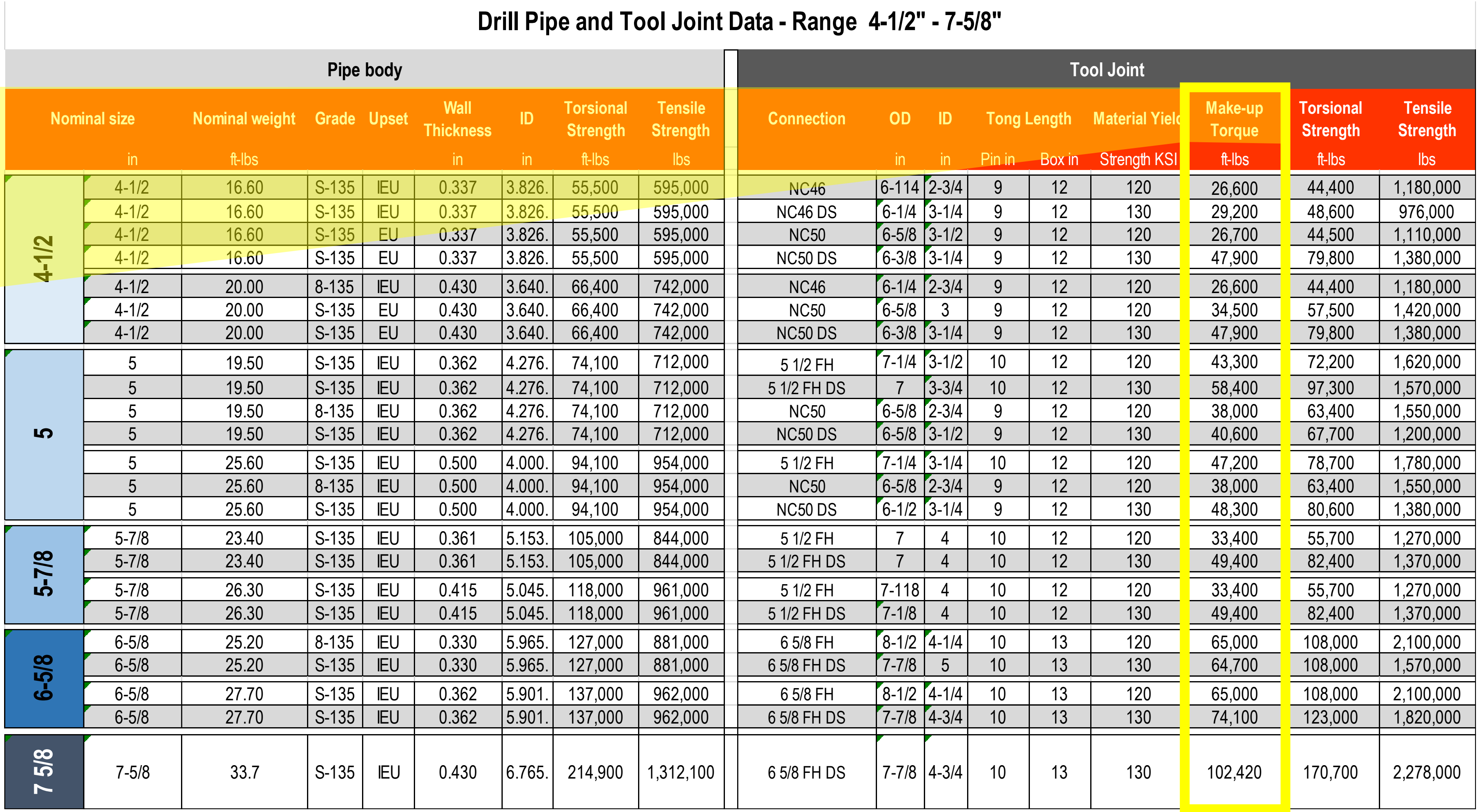
Buckling causes:

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



Distance

Make-up Torque



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

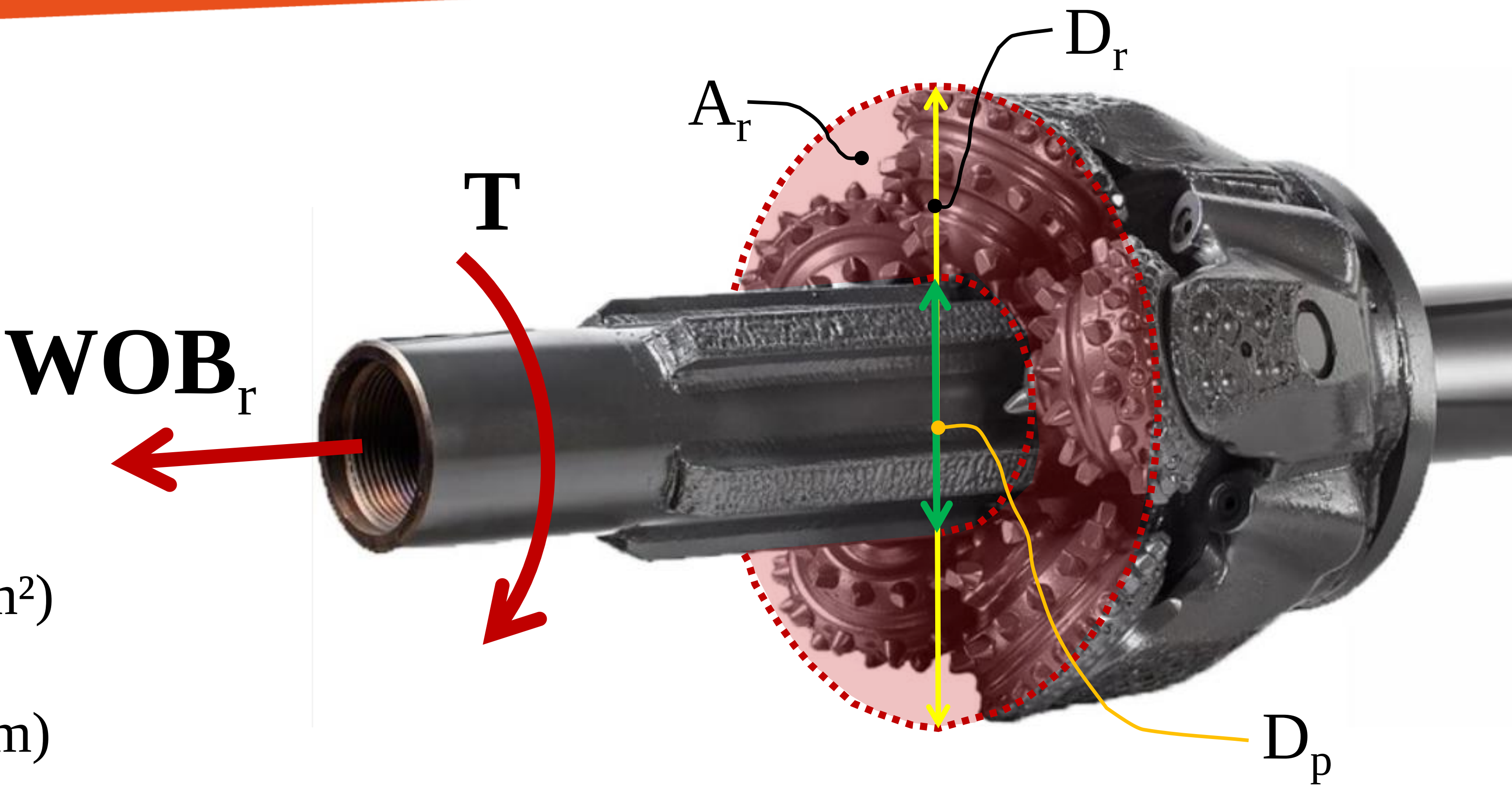
	Pipe body								Tool Joint								
	Nominal size	Nominal weight	Grade	Upset	Wall Thickness	ID	Torsional Strength	Tensile Strength	Connection	OD	ID	Tong Length		Material Yiel	Make-up Torque	Torsional Strength	Tensile Strength
	in	ft-lbs			in	in	ft-lbs	lbs		in	in	Pin in	Box in	Strength KSI	ft-lbs	ft-lbs	lbs
4-1/2	4-1/2	16.60	S-135	IEU	0.337	3.826.	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	IEU	0.337	3.826.	55,500	595,000	NC46 DS	6-1/4	3-1/4	9	12	130	29,200	48,600	976,000
	4-1/2	16.60	S-135	EU	0.337	3.826.	55,500	595,000	NC50	6-5/8	3-1/2	9	12	120	26,700	44,500	1,110,000
	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	1,380,000
	4-1/2	20.00	8-135	IEU	0.430	3.640.	66,400	742,000	NC46	6-1/4	2-3/4	9	12	120	26,600	44,400	1,180,000
	4-1/2	20.00	S-135	EU	0.430	3.640.	66,400	742,000	NC50	6-5/8	3	9	12	120	34,500	57,500	1,420,000
	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	1,380,000
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	IEU	0.362	4.276.	74,100	712,000	5 1/2 FH DS	7	3-3/4	10	12	130	58,400	97,300	1,570,000
	5	19.50	8-135	IEU	0.362	4.276.	74,100	712,000	NC50	6-5/8	2-3/4	9	12	120	38,000	63,400	1,550,000
	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	5 1/2 FH	7-1/4	3-1/4	10	12	120	47,200	78,700	1,780,000
	5	25.60	8-135	IEU	0.500	4.000.	94,100	954,000	NC50	6-5/8	2-3/4	9	12	120	38,000	63,400	1,550,000
	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	1,380,000
5-7/8	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	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	7-118	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	1,370,000
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	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	1,570,000
	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
	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	1,820,000
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	7-7/8	4-3/4	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/m^3 (Nm/m^3)

Basic parameter in the reaming process



A_r = crown cross section (m^2)
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

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

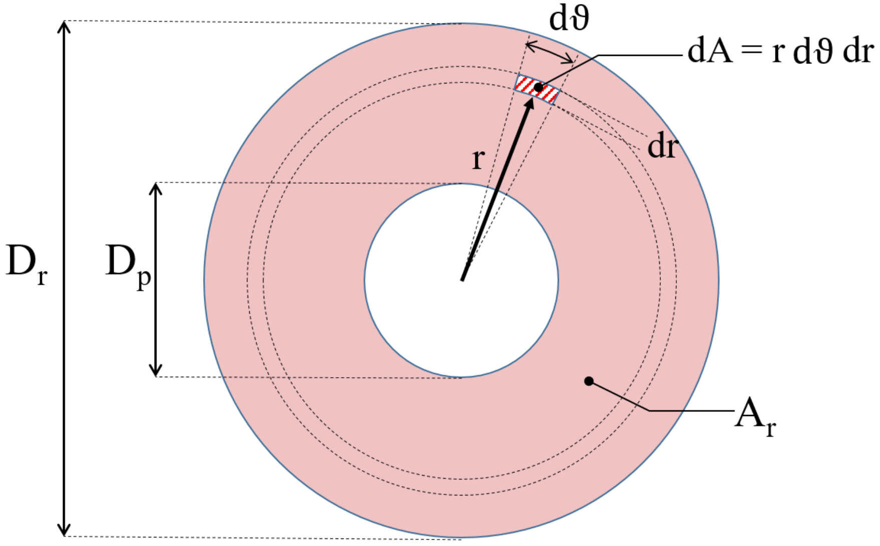
The product $\boldsymbol{MSE \cdot Q_s}$ (Nm/s = W) is then the mechanical power needed to drill under such operational parameters:

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

- $P_r = T\omega$ 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

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



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

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

$$\boxed{T = \frac{WOB_r \cdot \mu_r \cdot D_r}{k_r}} \qquad k_r = \frac{3(1-k^2)}{1-k^3} = \frac{3(k+1)}{(k^2+k+1)} \qquad 3 \ge k_r \ge 2\ \ for\ \ 0 \le k \le 1$$

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 t (78480 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 (ω = 3.14 rad/s)
- Pullback speed is s_p = 0.0022 m/s (8 m/h),

$Q_s = ROP \cdot A_r$ = $8.33 \cdot 10^{-4}$ m³/s

the power P needed at the reamer is given by:

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

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

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

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Thank you!