



EPRG-PRCI-APGA

23rd Joint Technical Meeting

Edinburgh, Scotland • 6–10 June 2022

Understanding damage to underground
pipelines due to horizontal directional drilling

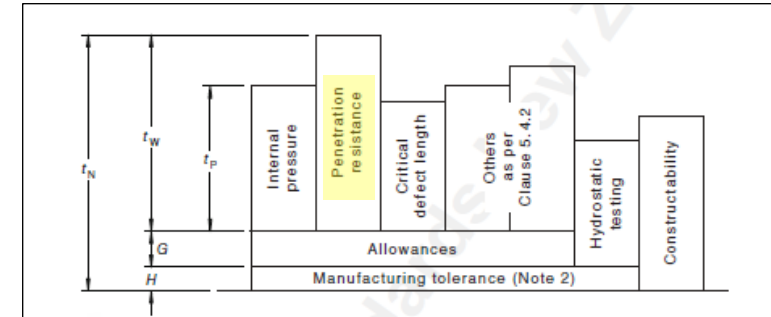
7 June 2022



Research Motivation

AS2885 requires explicit understanding of pipeline response to all external interference threats, throughout pipeline life cycle:

- Design
- Integrity Management
- Safety Management Studies
- Land Development Planning around pipelines



- (ii) Dimensions of the puncture hole resulting from the maximum identified THREAT, and the resulting failure mode. The failure mode due to penetration may be—
- (A) a RUPTURE, if maximum hole length \geq CRITICAL DEFECT LENGTH;
- (B) a leak, if maximum hole length $<$ CRITICAL DEFECT LENGTH; or

- (a) Calculations For factor B (values) calculate the excavator size and tooth type(s) to achieve the following:

In all locations, the design shall assess means of limiting the maximum energy release rate through a pipeline segment in the event of a loss of containment in that segment resulting from the largest equivalent DEFECT produced by the THREATS identified in that location.

Penetration.

Breach of the 'No RUPTURE' requirement [i.e. the smallest machine which can penetrate with a tooth that creates a hole greater than 2/3 of CRITICAL DEFECT LENGTH, so that CDL exceeds 150% of hole length in accordance with Clause 4.9.2(b)].

- (iii) RUPTURE (i.e. the smallest machine which can penetrate with a tooth that creates a hole greater than the CRITICAL DEFECT LENGTH).

NOTE: While this Clause is focused on pipe damage by penetration, the usual consequence of an excavator attack is a DENT and GOUGE. DENT-GOUGE combinations work synergistically to significantly lower the pressure at which a pipe fails and therefore can be a particularly dangerous form of damage. While there has been considerable research on the DENT-GOUGE consequence of an excavator attack, it has not developed to a stage where design information can be included in this Standard. Section 11 of this Standard and AS 2885.3 have specific requirements relating to DENT and GOUGE combinations.

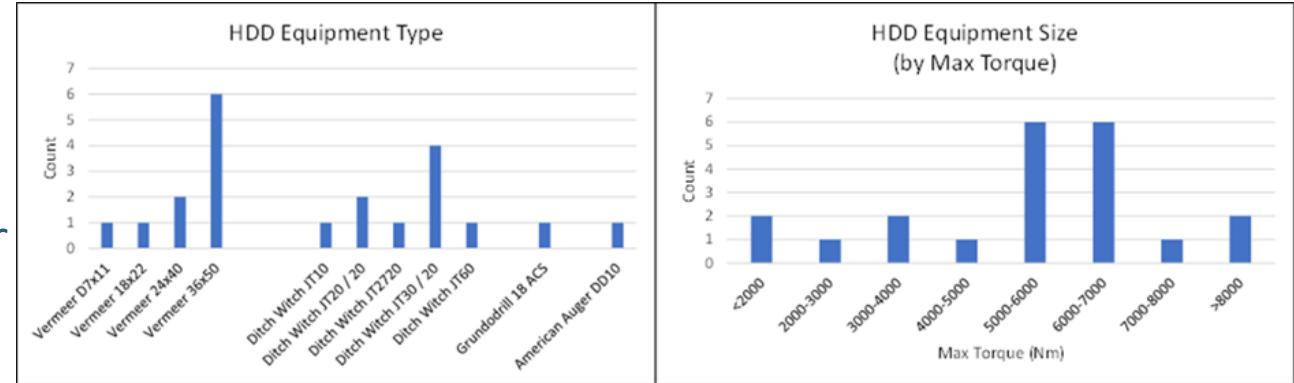
- (b) The thickness required for resistance to penetration by the design THREAT, if this is used as a method of providing external interference protection in accordance with Clause 5.4. In T1 and T2 LOCATION CLASSES, where thickness is the method chosen to provide penetration resistance, the thickness necessary to provide a minimum level of penetration resistance.



HDD Equipment – Target Rig Sizes

Target HDD Rig Sizes for Research:

- Utility installation in residential areas
- Typical pilot holes 60 – 120mm diameter
- Typical utility 60 – 250mm diameter



Parameters	HDD Equipment Types	
	Vermeer D36x50	Ditch Witch JT30
Maximum Torque (Nm)	6,700	5,400
Maximum Thrust / Pullback (kN)	160	110 / 130
HDD Rod Diameter (mm)	60 - 67	60



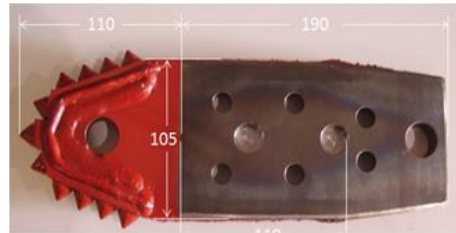
HDD Equipment – Bit Types

HDD Bit types and Sizes:

- Typical for utility rigs for range of ground conditions



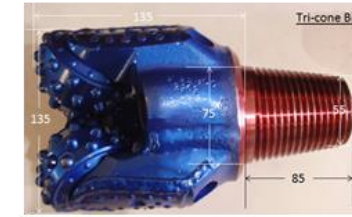
2.5" Steep Taper



4" Steep Taper Ultra



4.25" Eagle Claw



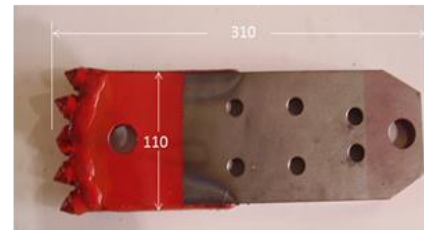
5.5" Tri Cone



2.5" Sand Bit



2.5" Barracuda



4" Bearclaw



PDC

Soft / Sandy Soil

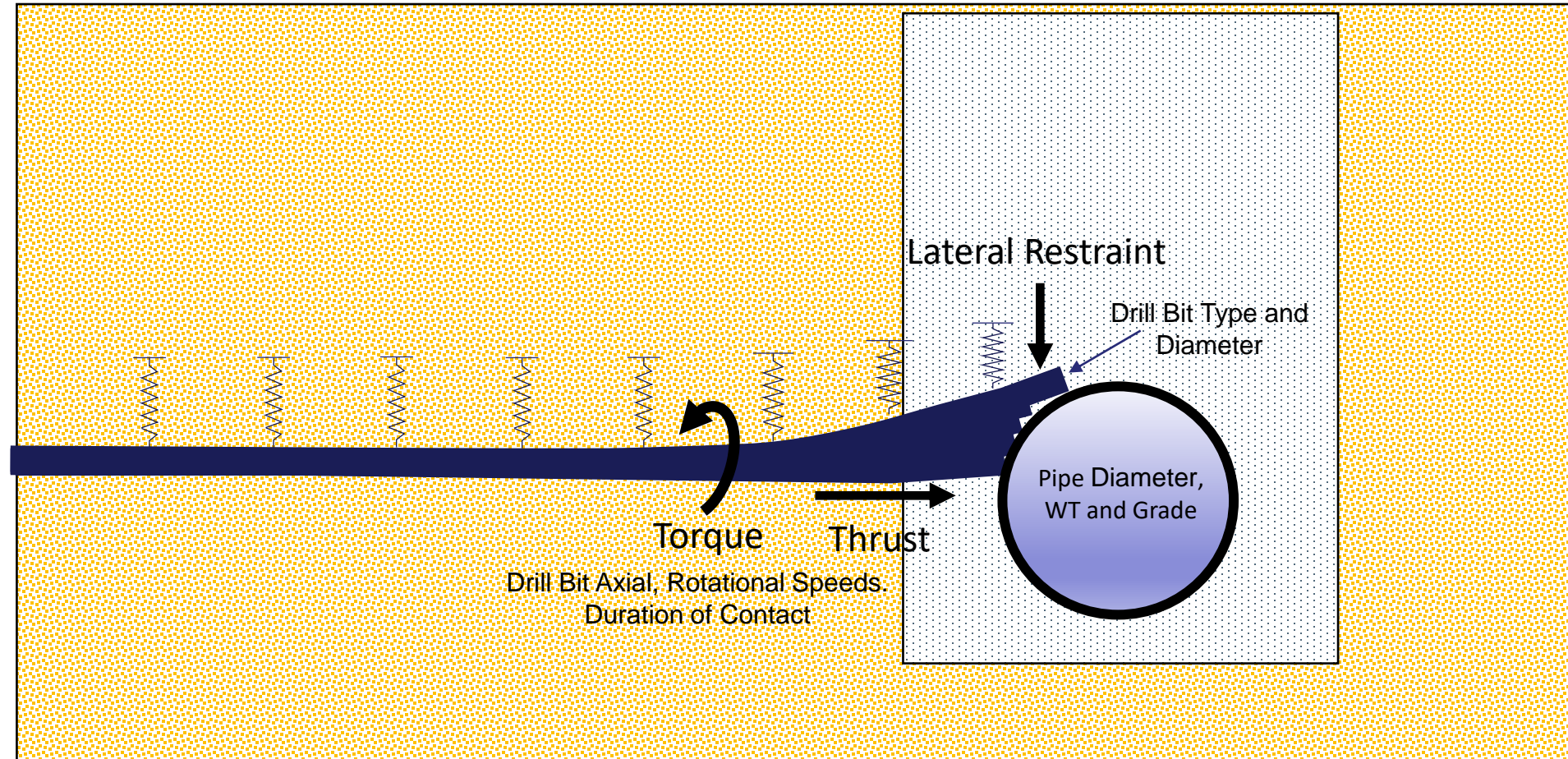
Medium Soil / Cobbles

Hard Soil / Soft Rock

Hard Rock



HDD – Pipeline Interaction : Forces



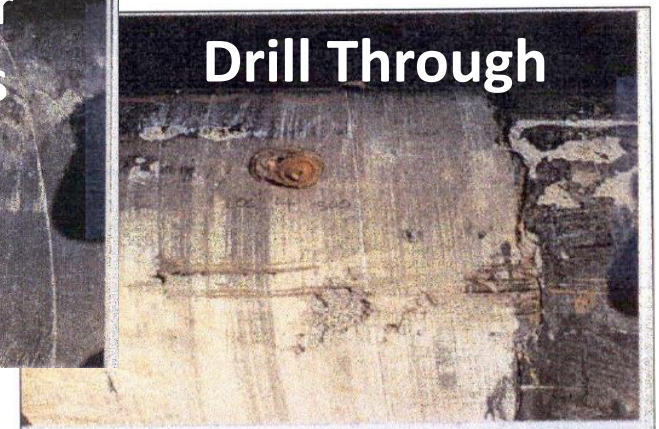
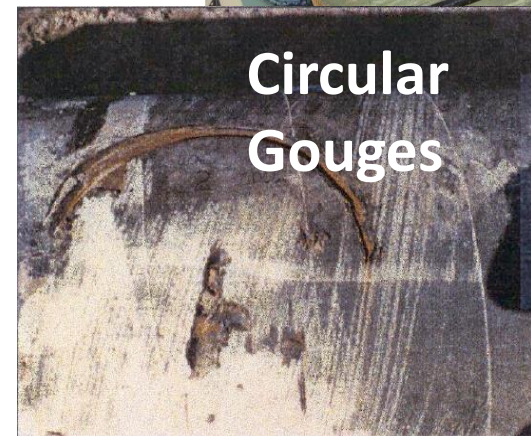
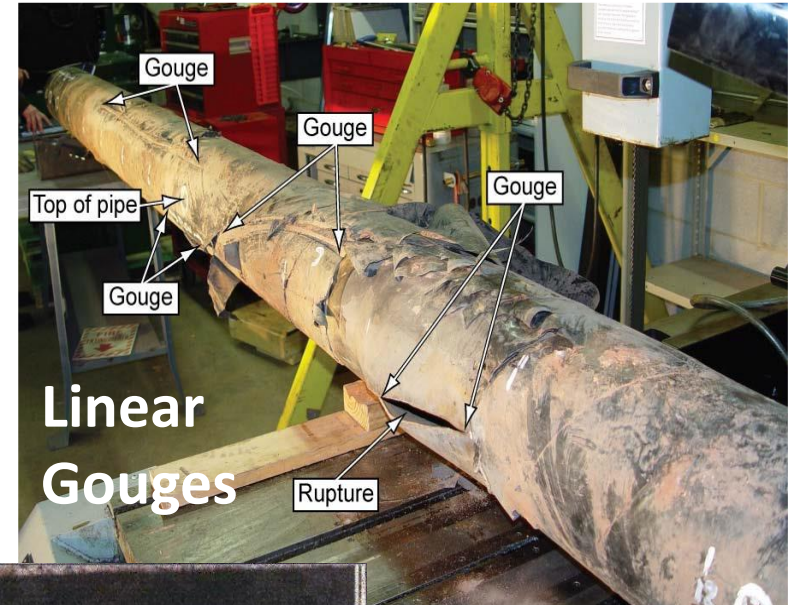
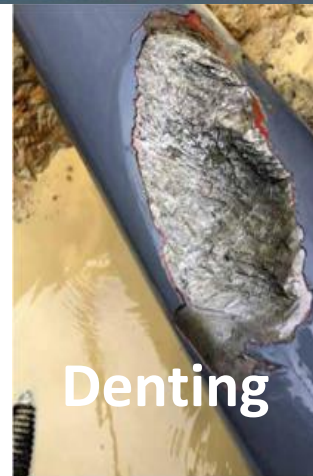
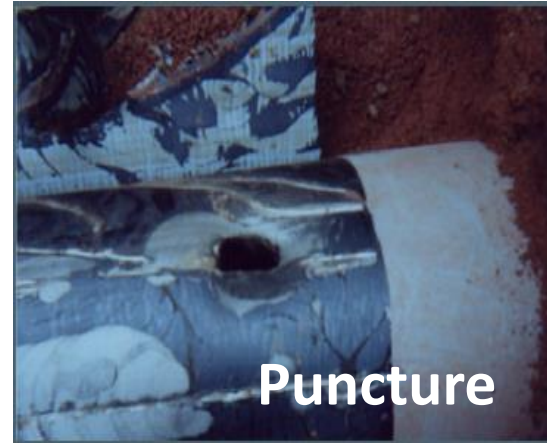
HDD – Pipeline Interaction : Damage type

Research considered all potential damage types :

- Gouges
- Puncture
- Drill through
- Denting

Aim to define most credible damage type and failure mode

Ref: Brooker 2002

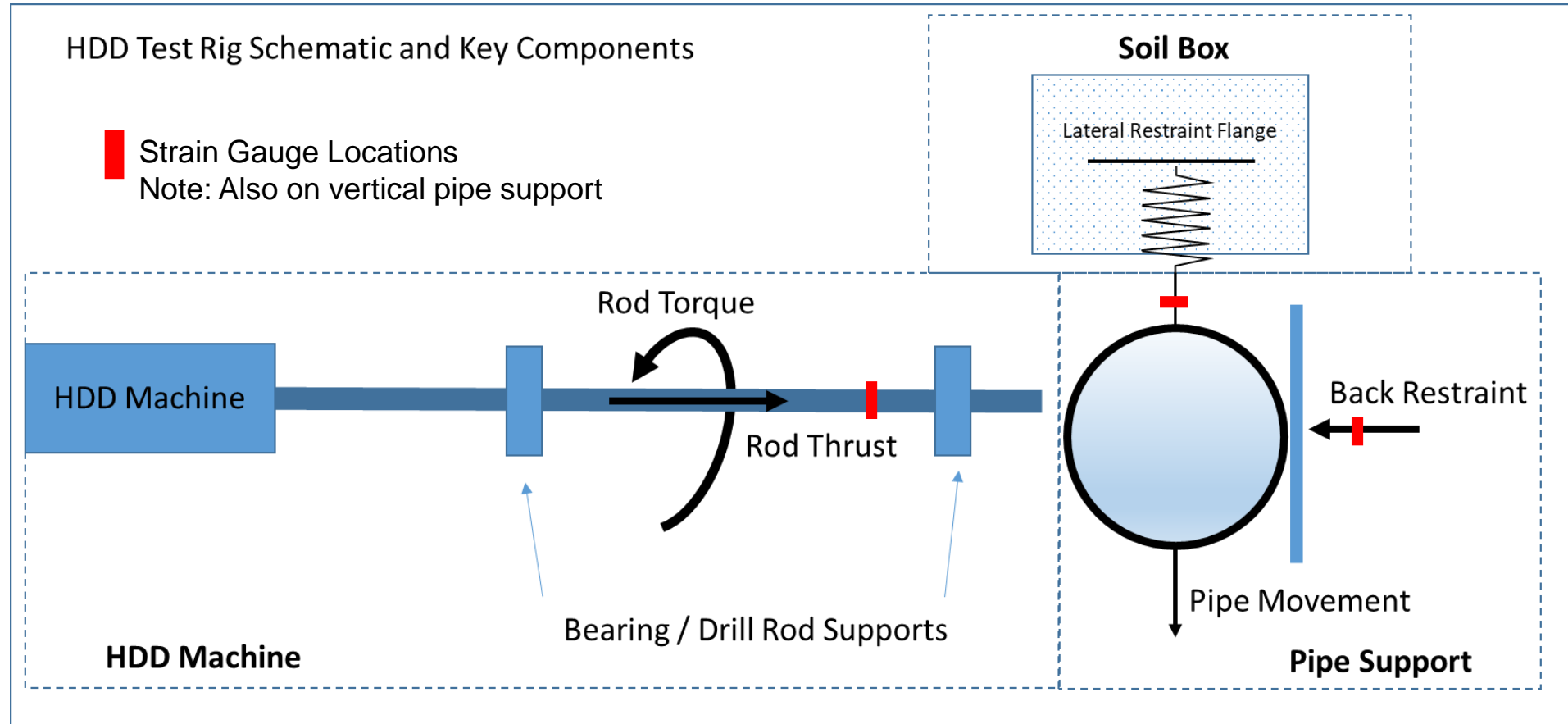


Ref: NTSC/PAB-07/02 2004

Ref: Tas Gas Network, The Australian Pipeliner 2018

Ref: Gas & Fuel Field Trials 1982

HDD Experimental Test Rig : Schematic





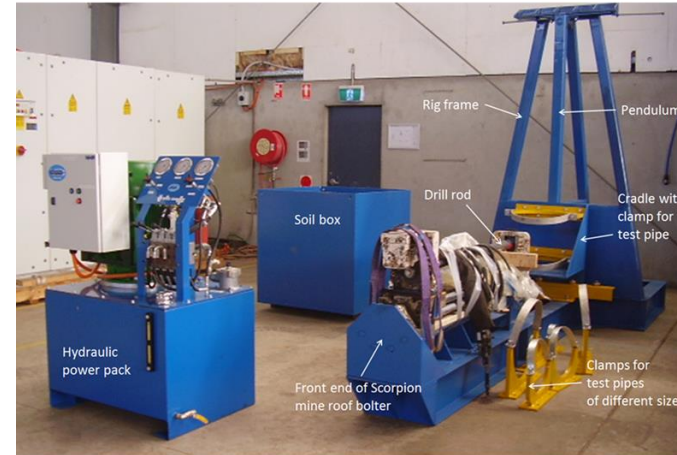
HDD Experimental Test Rig : Test Rig

Phase 1 Test Rig:

- Hydraulic rock drill
 - Max Torque = 400Nm

Phase 2 Test Rig:

- CMS 3020 HDD machine
 - Max Torque = 5000Nm
 - Max Thrust = 150kN

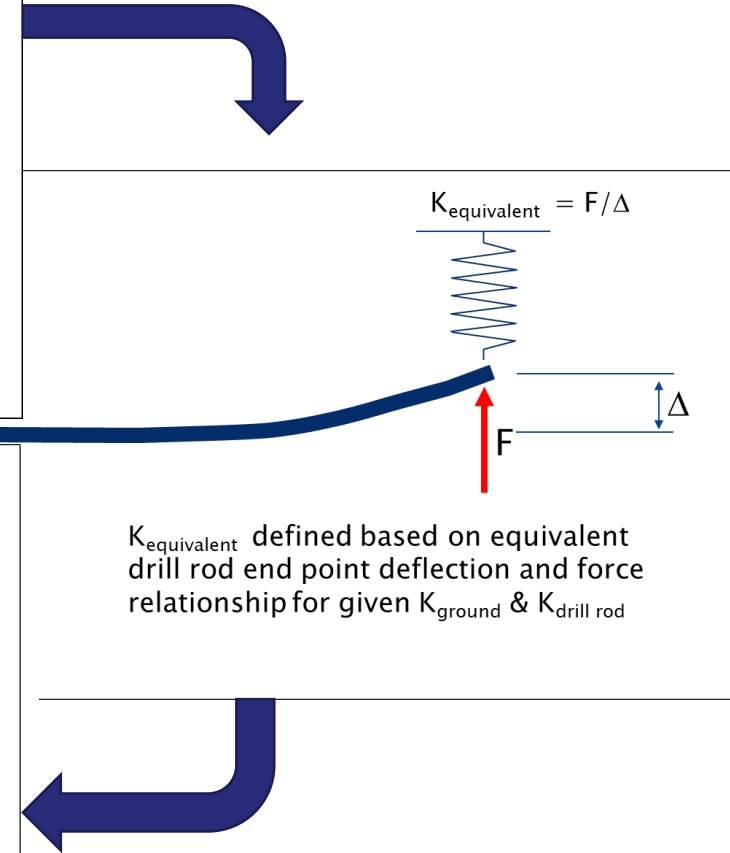
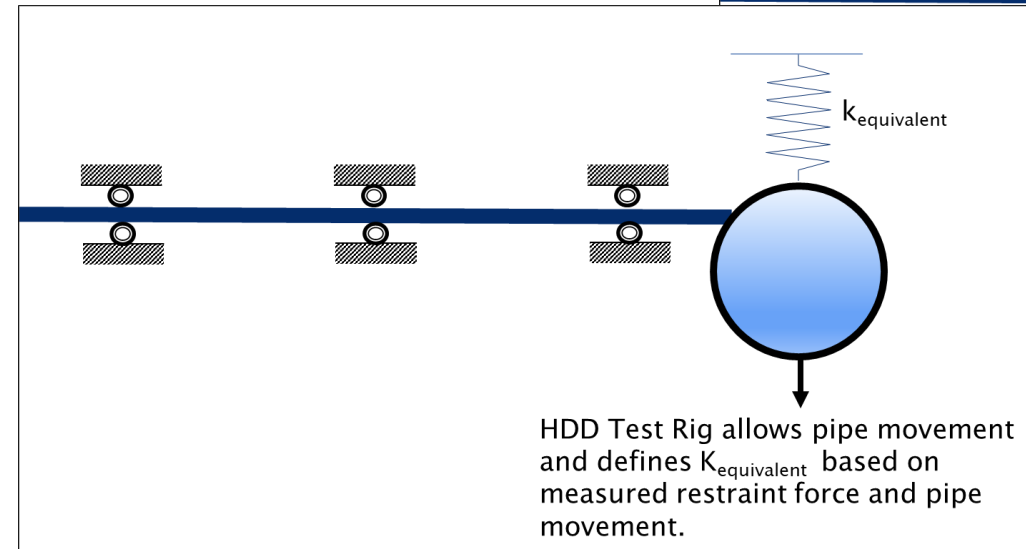
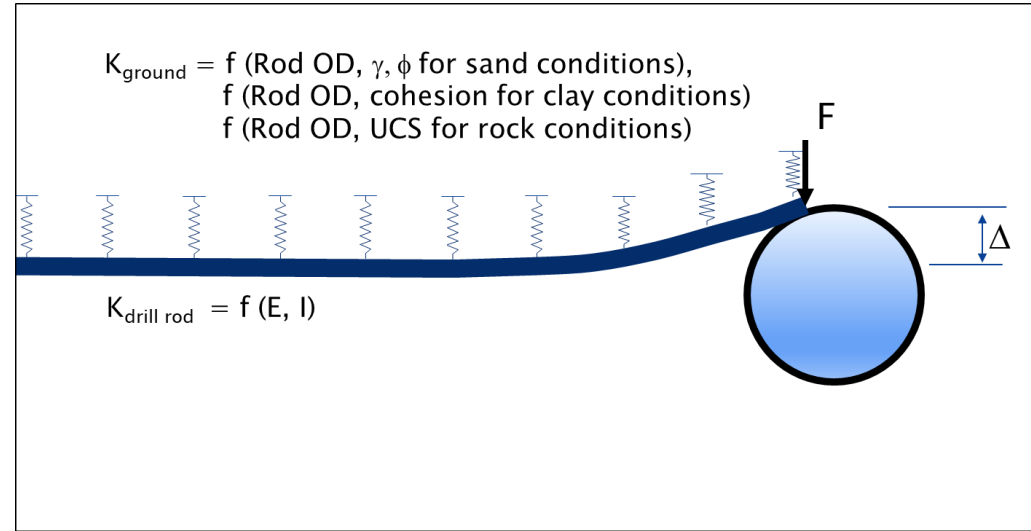


HDD Experimental Test Rig : Lateral Restraint Modelling

Test conditions related to actual ground conditions through K_{eq} ,

where:

- $K_{eq} = F/\Delta$ at HDD tip





HDD Experimental Tests : Test Parameters

Total of 130 tests encompassing 40 parameter scenarios :

Parameter	Test Range
Pipe Diameter	DN150 to DN500
Wall Thickness	4.8mm to 12.2mm
Grade	X42 to X70
External Coatings	FBE, HDPE, Naprock
Rotational HDD speed	60 – 180rpm
Axial HDD speed	5mm/sec
Initial impact position	0 – 150mm
Soil Restraint Flange Diameter	200 to 600mm





HDD Experimental Tests : Video

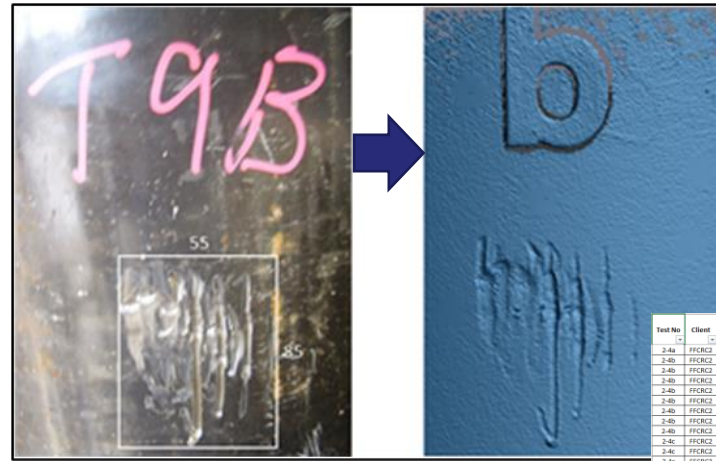
Bearclaw



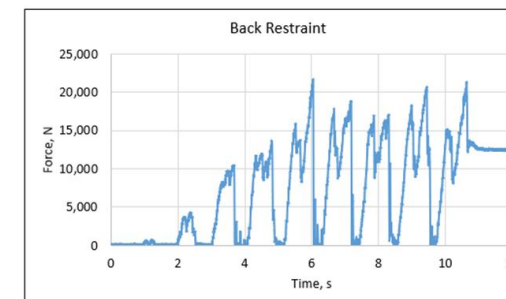
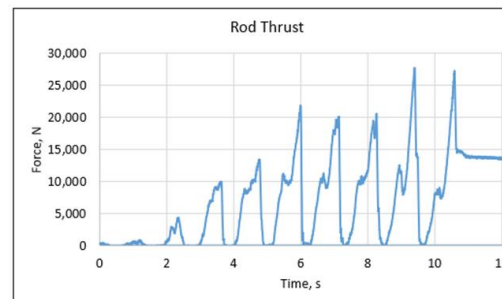
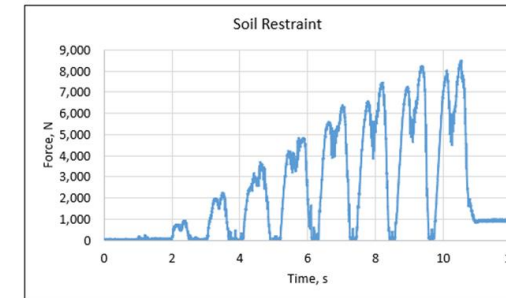
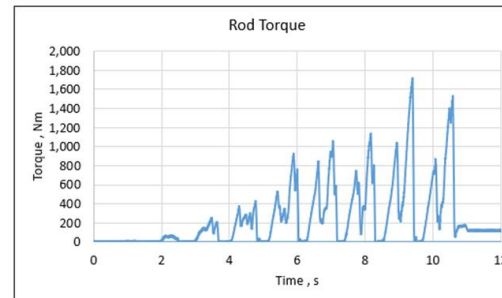
HDD Experimental Tests : Test Data

Test Data:

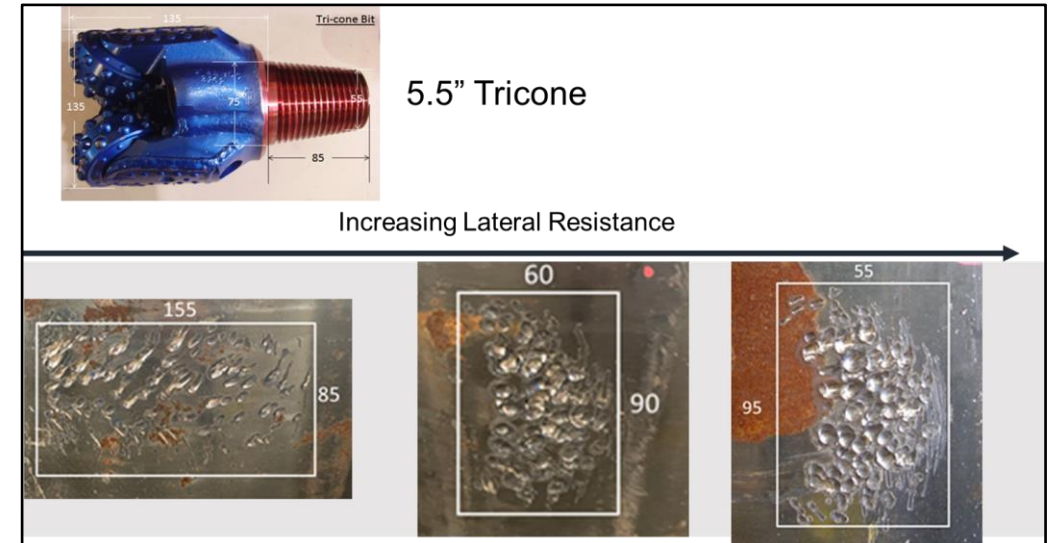
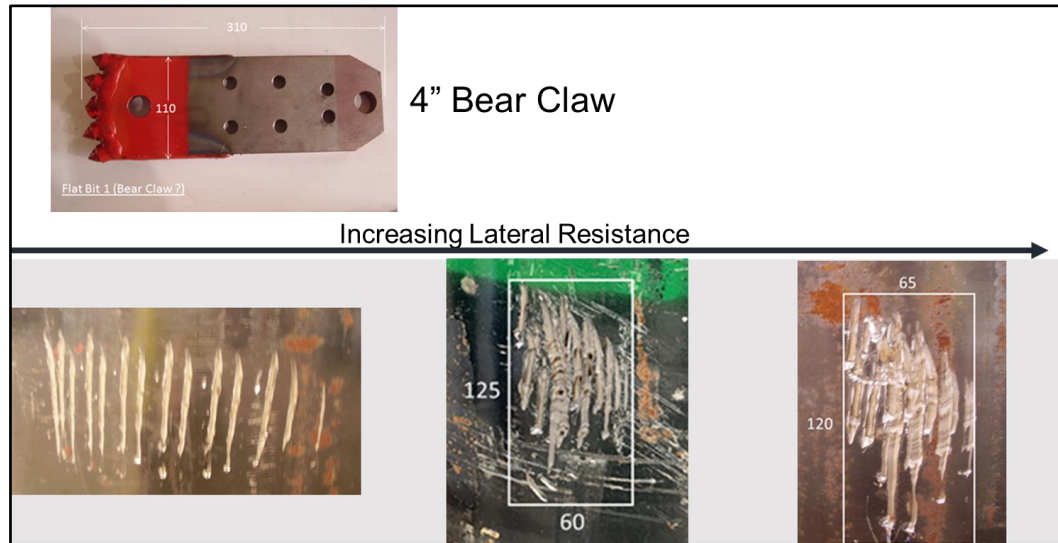
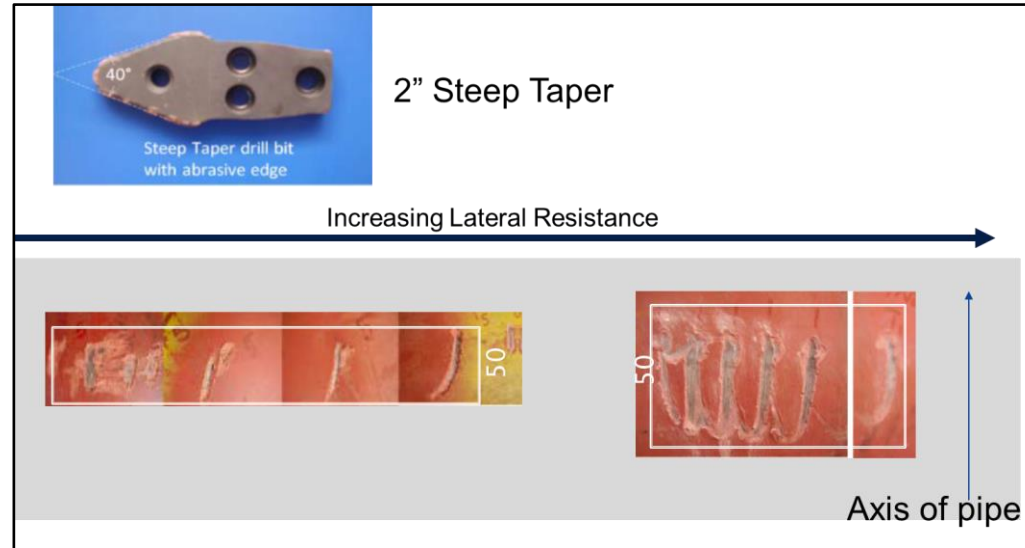
- All gouges measured with laser scanner
- Force data for each strike recorded and correlated with gouges
- Compiled database of force-gouge relationships for approx. 600 gouges



Test No	Client	Date	Pipe OD	WT	Grade	SMYS	Coating	Coating thk	Bit Type	Bit Dia	Tip Rad	Rotation Speed	Axial Speed	Offset	Flange dia	Gauge No	Gauge Position	Rod Torque	Rod Thrust	Soil Restraint	Back Restraint	Vertical Force	Connect d Lat Force	Lateral Deflection	Reff	Flow Force
2-4a	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	8	27	285	13900	6250	17000	14000	7800	5	1040	9047.61905
2-4b	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	1	16	135	5000	5500	8000	7000	2350	2	3200	4205.71429
2-4c	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	2	19	250	30000	3800	12000	12000	3800	4	915	7956.50794
2-4d	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	3	21	285	12500	4500	15000	14000	5700	5	1140	9047.61905
2-4e	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	4	24	360	12500	5000	17000	17000	7050	5	1404	11426.5714
2-4f	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	5	26	345	14000	5000	19000	15000	7050	10	488	10793.181
2-4g	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	6	29	335	14000	5800	15500	13800	7200	10	726	10834.5036
2-4h	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	7	31	360	14000	6700	14900	13500	7600	20	786	11433.5714
2-4i	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	8	34	335	12900	6400	13900	12000	7800	10	786	10834.5036
2-4j	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	1	16	95	4400	1200	5700	5500	1740	2	870	3015.87302
2-4k	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	2	18	190	9600	2300	11000	9500	3900	5	612	4015.74603
2-4l	FFRC2	6-Apr-22	508	9.5	X52	339	FBE	0.5	2in Taper	2	11.5	40	5	100	400	3	20	305	12200	3900	14500	15500	4800	5	996	9682.53946
Soil Restraint																										
11.5	40	5	100	400	4	22	320	13100	5100	16500	14300	6900	10	466	10158.7392											
11.5	40	5	100	400	5	24	330	14700	5400	16100	13900	6700	12	505	9641.20984											
11.5	40	5	100	400	6	26	340	15400	5800	17000	14200	7200	12	605	10793.6508											
11.5	40	5	100	400	7	28	350	16000	6200	17900	15200	7500	12	655	11433.5714											
11.5	40	5	100	400	8	30	370	16500	6600	18800	16500	7900	12	695	12146.0117											
11.5	40	5	100	400	9	33	385	17800	6400	19900	17100	7800	12	695	11287.3016											
11.5	40	5	100	400	10	35	400	18500	6700	20800	18300	8300	12	695	10834.5036											
11.5	40	5	100	400	11	37	420	19200	6900	21100	19100	8300	12	715	10158.7392											
11.5	40	5	100	400	12	39	430	20200	7000	21100	20300	8700	12	715	10158.7392											
11.5	40	5	100	400	13	41	430	20500	7200	21000	20500	8900	12	735	9641.20984											
11.5	40	5	120	500	1	21	40	2000	900	8400	2000	1100	1	1180	1091.7019											
11.5	40	5	120	500	2	23	170	4000	2000	6900	7000	2300	2	1350	5396.4254											
11.5	40	5	120	500	3	24	220	5000	2000	8300	9500	3700	3	1260	6984.12698											
11.5	40	5	120	500	4	26	300	7500	4200	12000	11900	5400	3	1780	9513.80973											
11.5	40	5	120	500	5	28	310	9000	5100	1300	12500	6420	5	1284	9641.20984											
11.5	40	5	120	500	6	30	340	10500	6000	14000	13800	7000	7	1071.42857	10793.6508											
11.5	40	5	120	500	7	31	380	11500	6900	14600	13100	8300	8	1072.5	12064.4912											



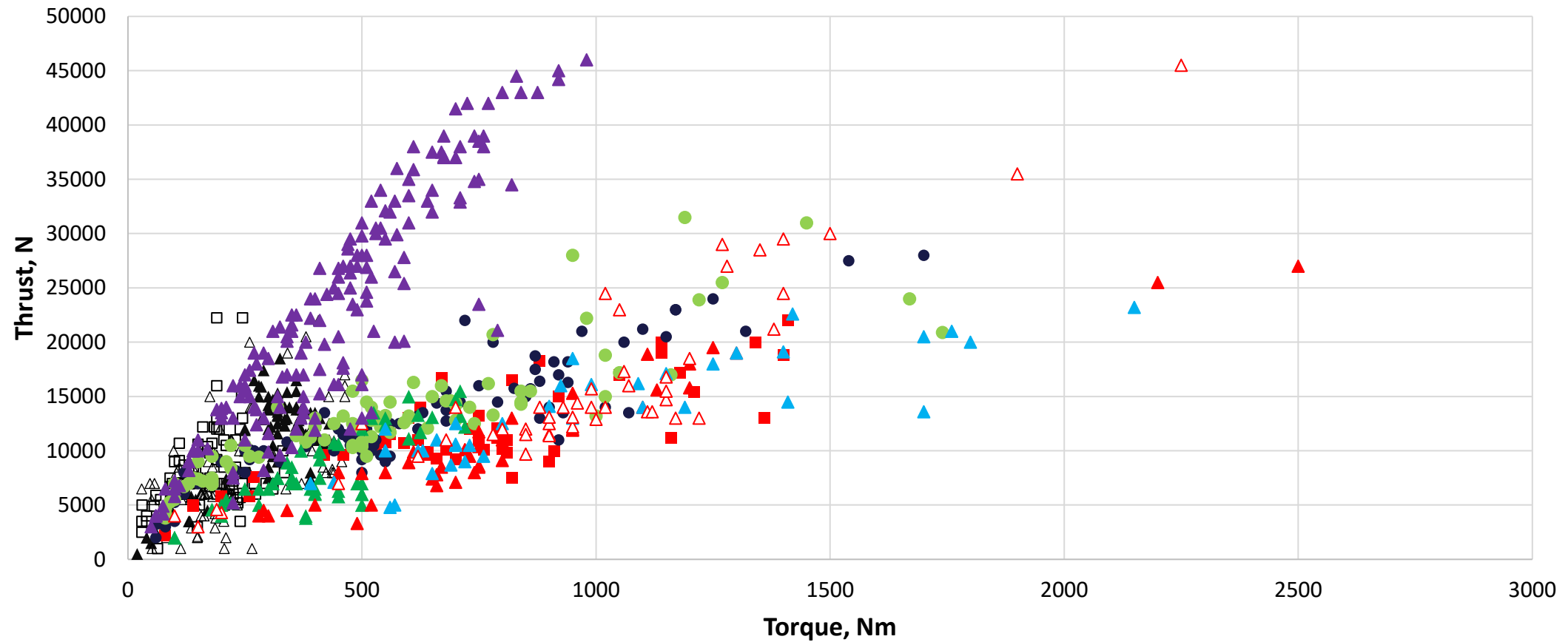
HDD Experimental Tests : Observed Damage





HDD Test Results: Rod Torque and Thrust

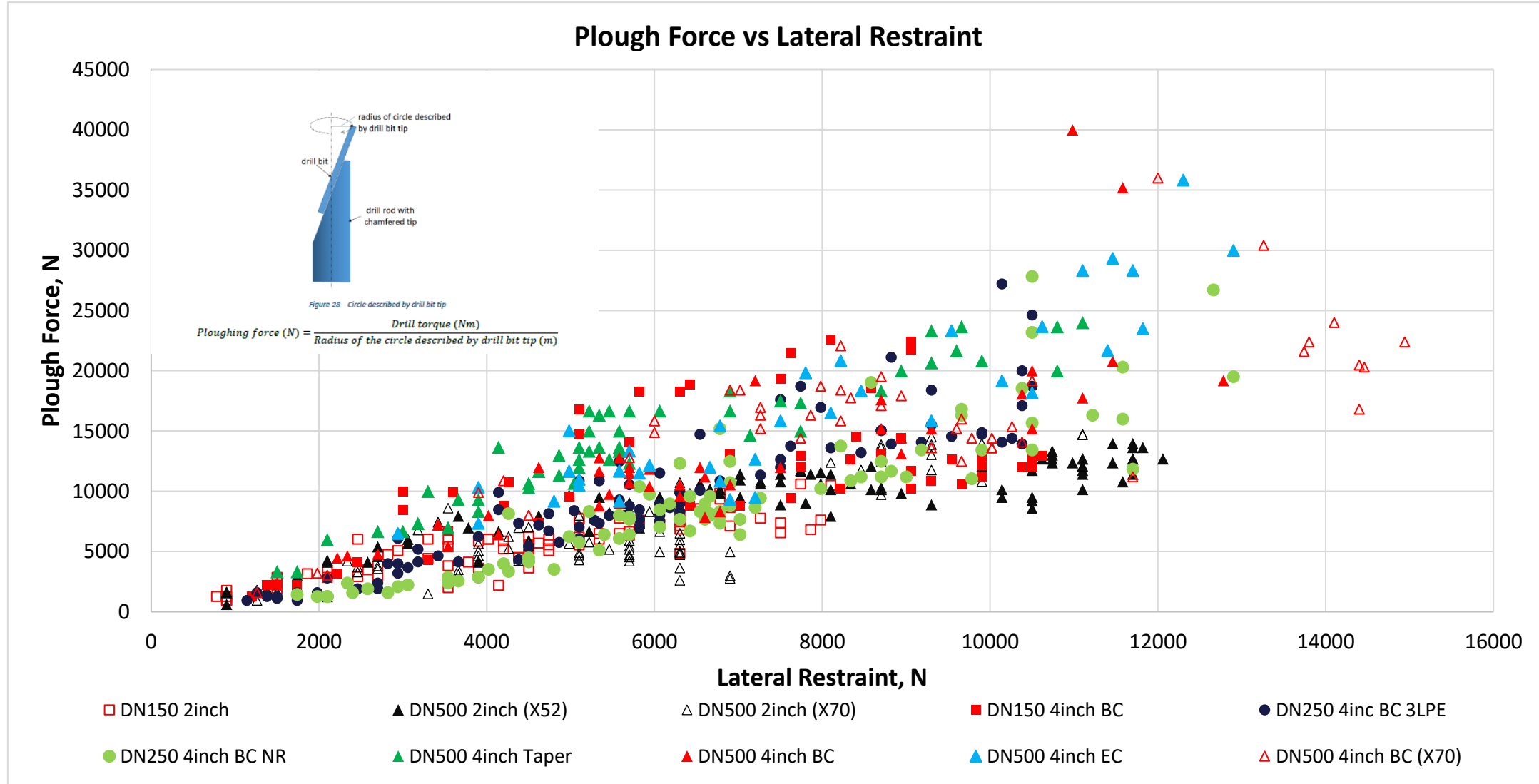
Thrust vs Torque



- | | | | | | |
|---------------------|---------------------|---------------------|------------------------|-----------------------|---------------------|
| □ DN150 2inch | ▲ DN500 2inch (X52) | △ DN500 2inch (X70) | ■ DN150 4inch BC | ● DN250 4inc BC 3LPE | ● DN250 4inch BC NR |
| ▲ DN500 4inch Taper | ▲ DN500 4inch BC | ▲ DN500 4inch EC | △ DN500 4inch BC (X70) | ▲ DN500 5inch Tricone | |



HDD Test Results: Lateral Restraint and Plough Force

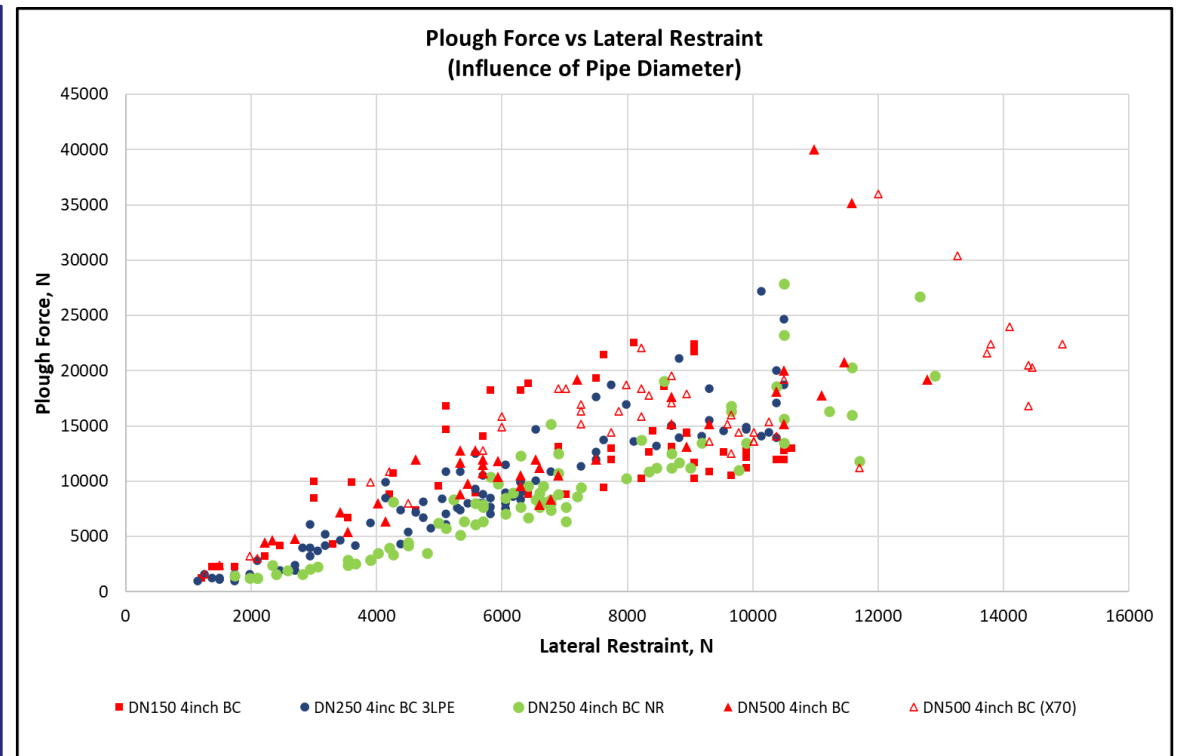
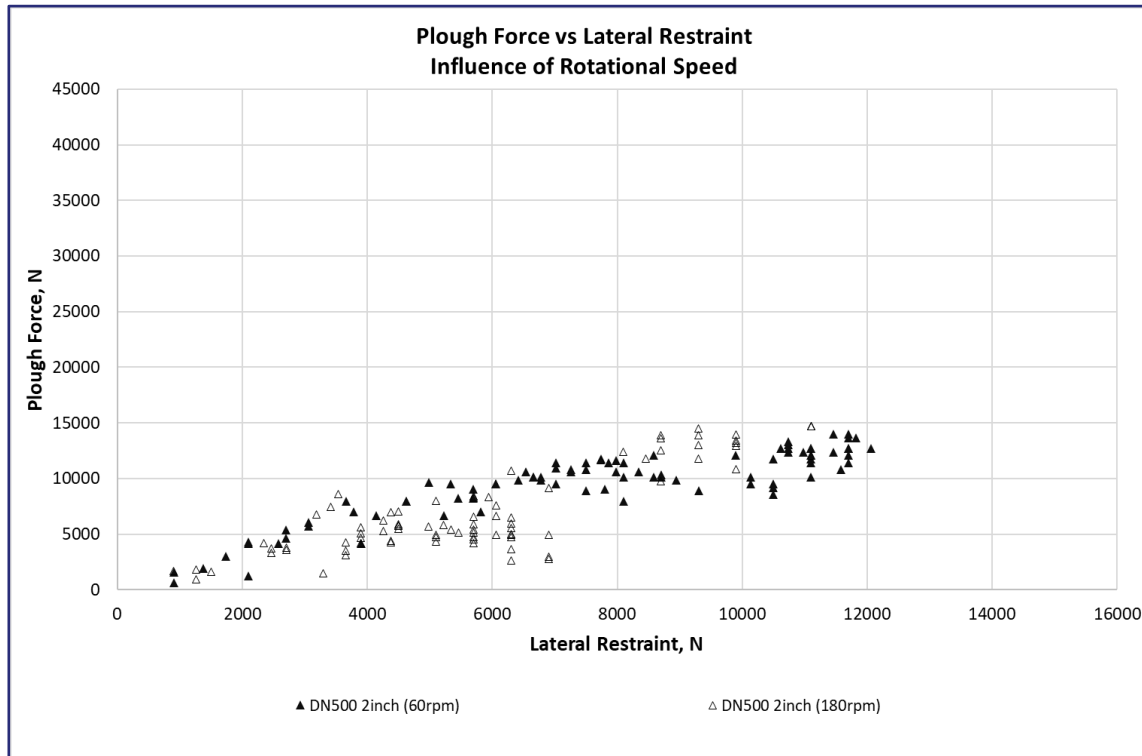




HDD Test Results: Influence on Plough Force

Key Findings 1:

- Strong correlation with Lateral Restraint
- No observable influence from Rotational speed, Pipe OD

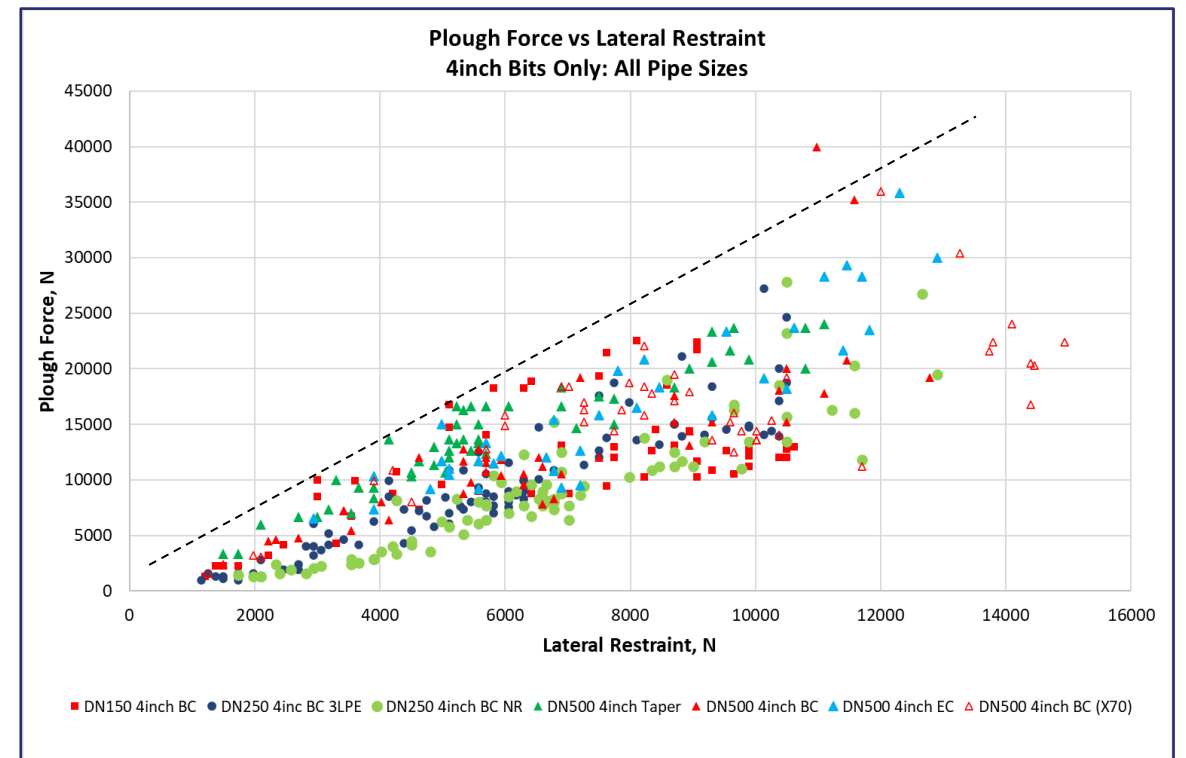
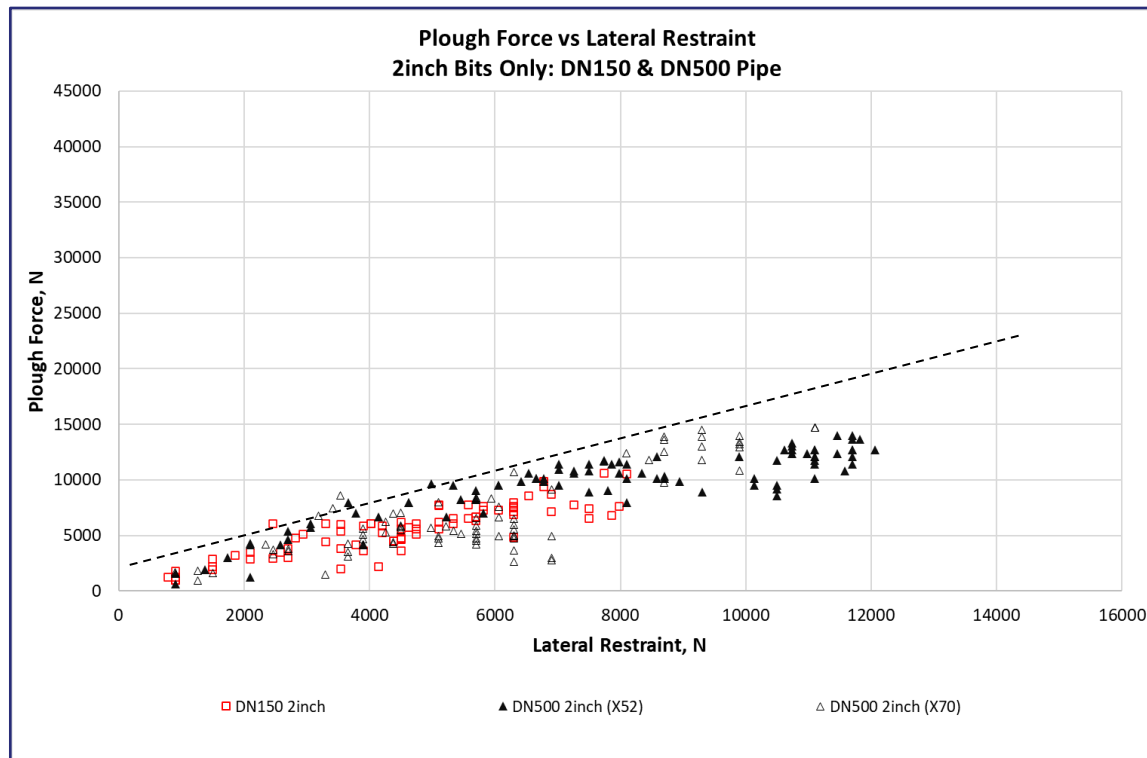




HDD Test Results: Influence on Plough Force

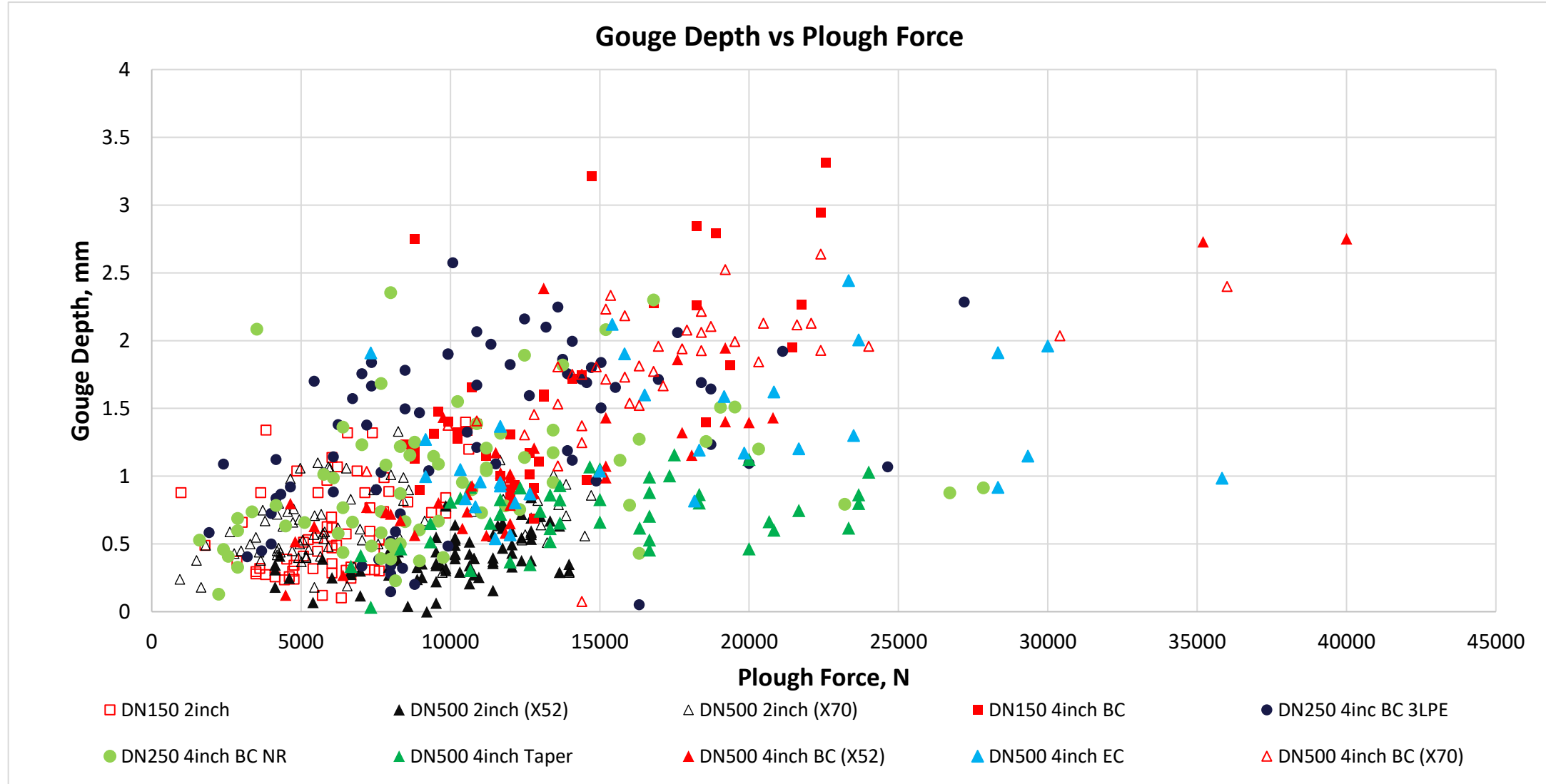
Key Findings 2:

- Influenced by Bit Type (i.e. carbide bit vs flat blade).
- Not Bit Size (tip radius)

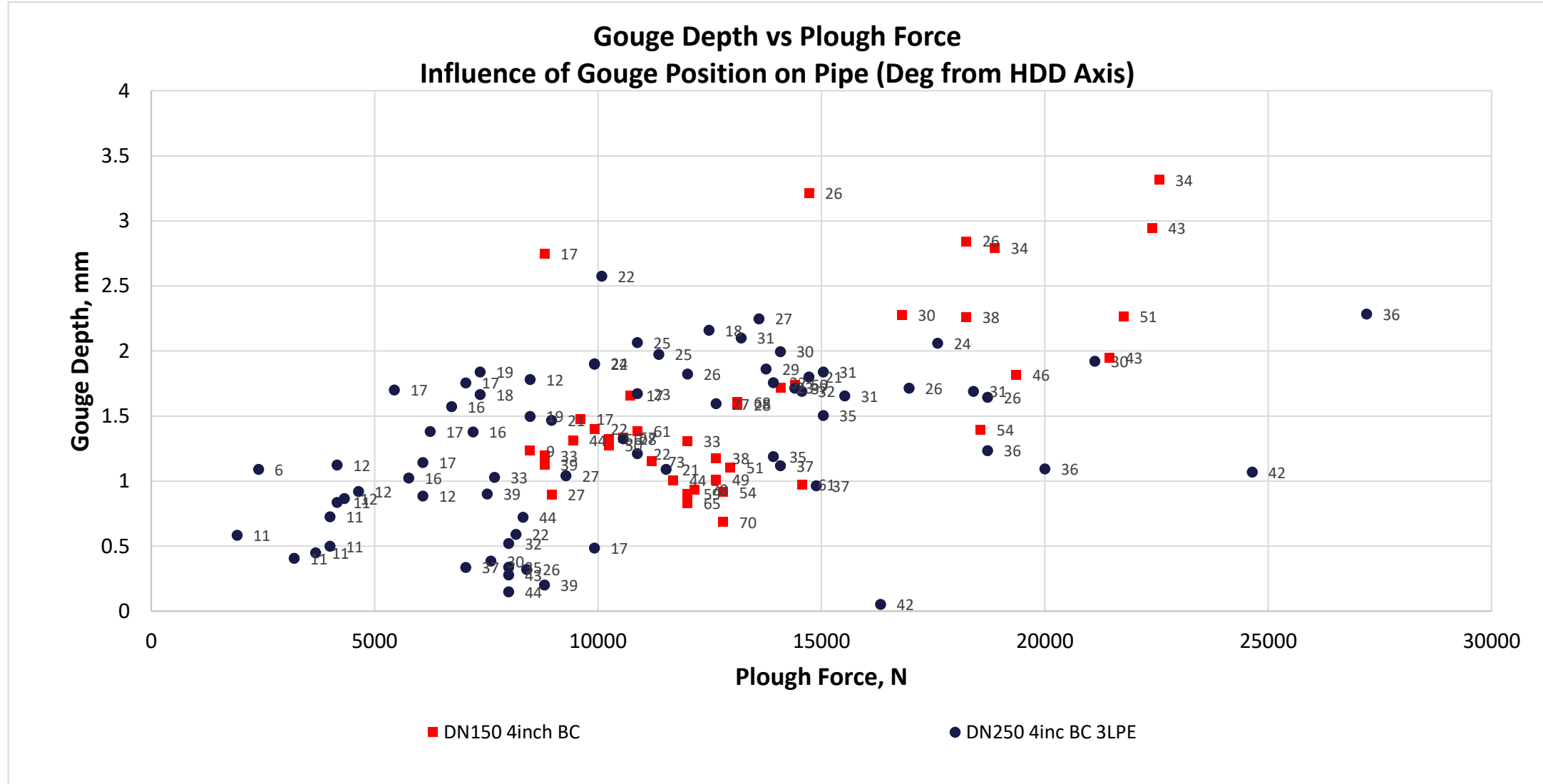




HDD Test Results: Plough Force and Gouge Depth



HDD Test Results: Influence on Gouge Depths

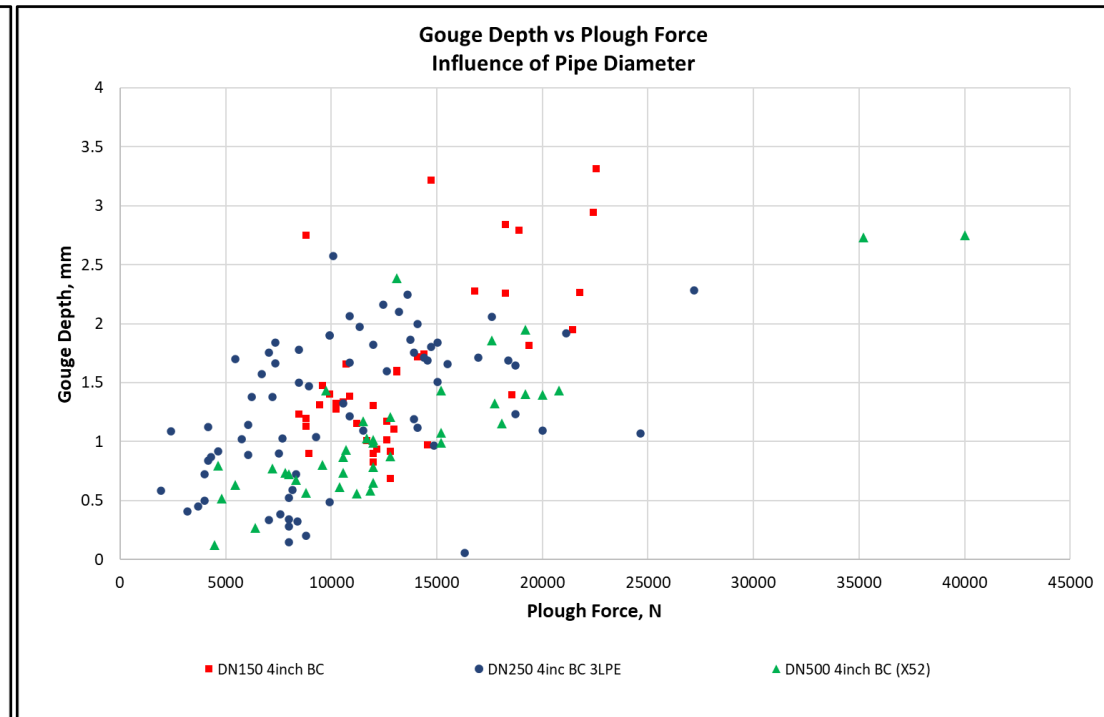
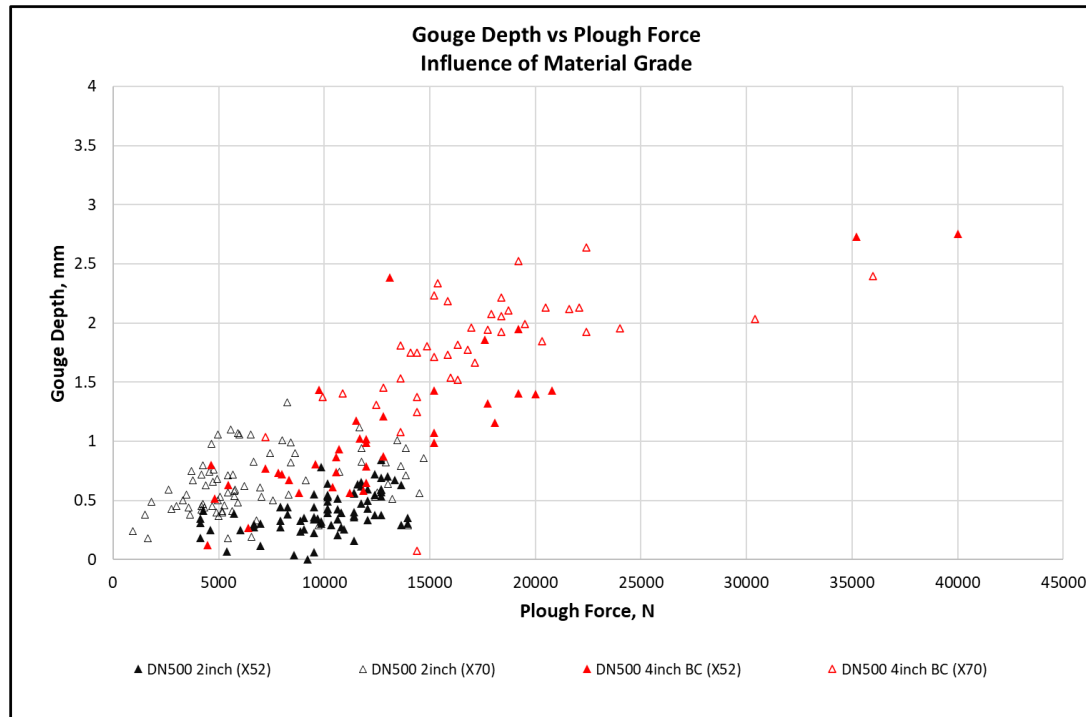




HDD Test Results: Influence on Gouge Depths

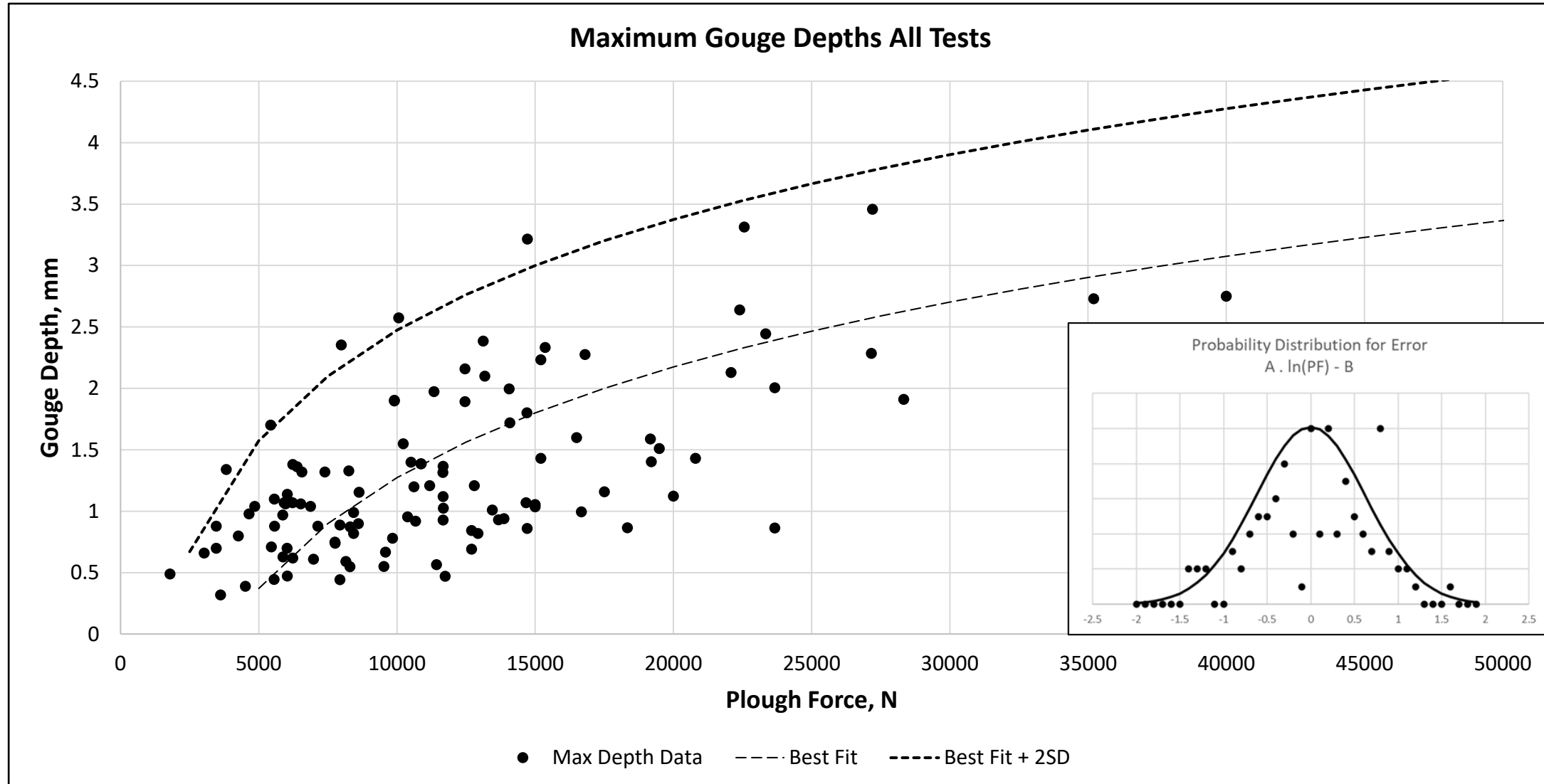
Key findings:

- No observed influence from pipe diameter, material grade, coating type.





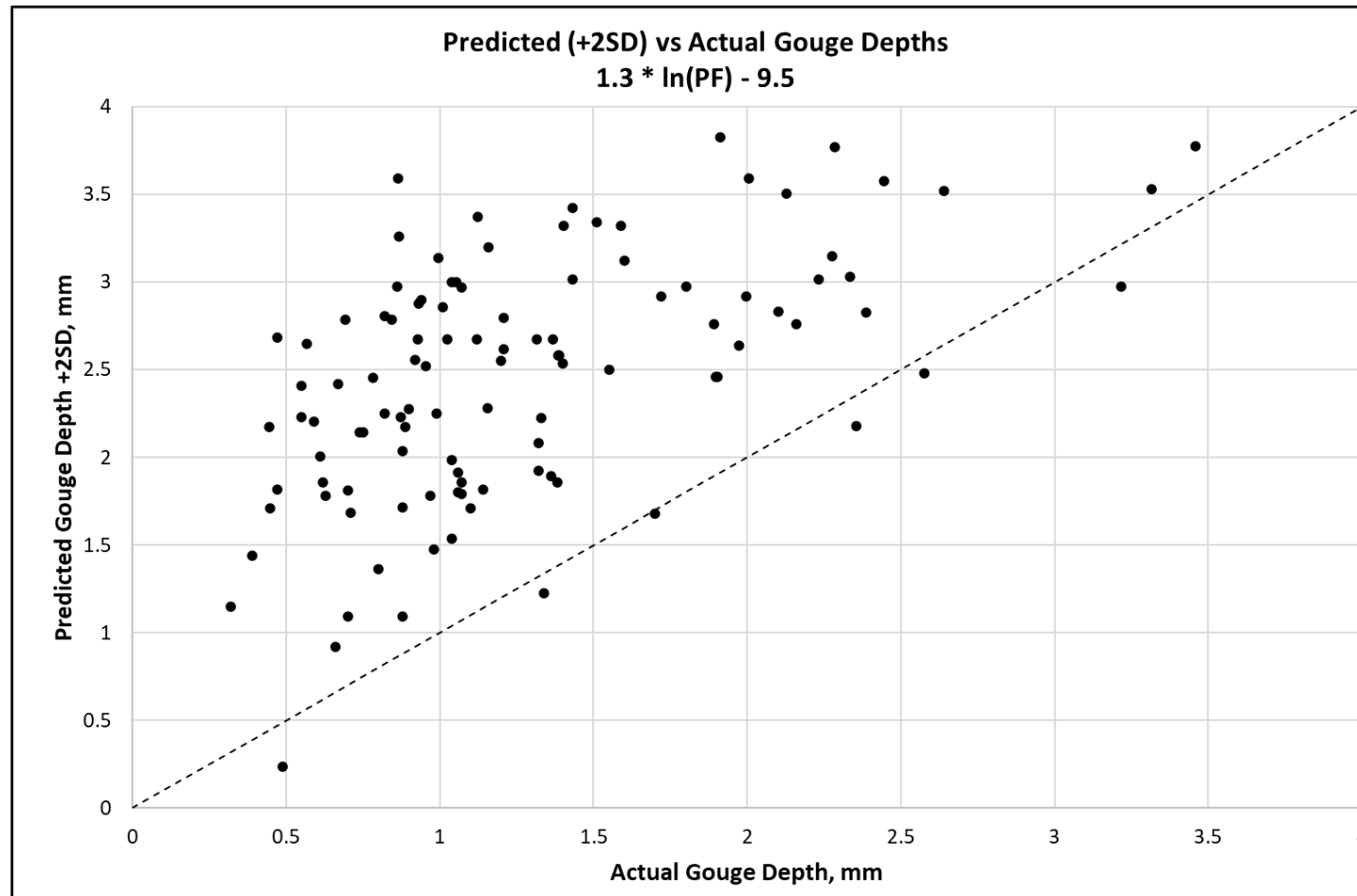
HDD Test Results: Gouge Depth Relationship





HDD Test Results: Gouge Depth Relationship

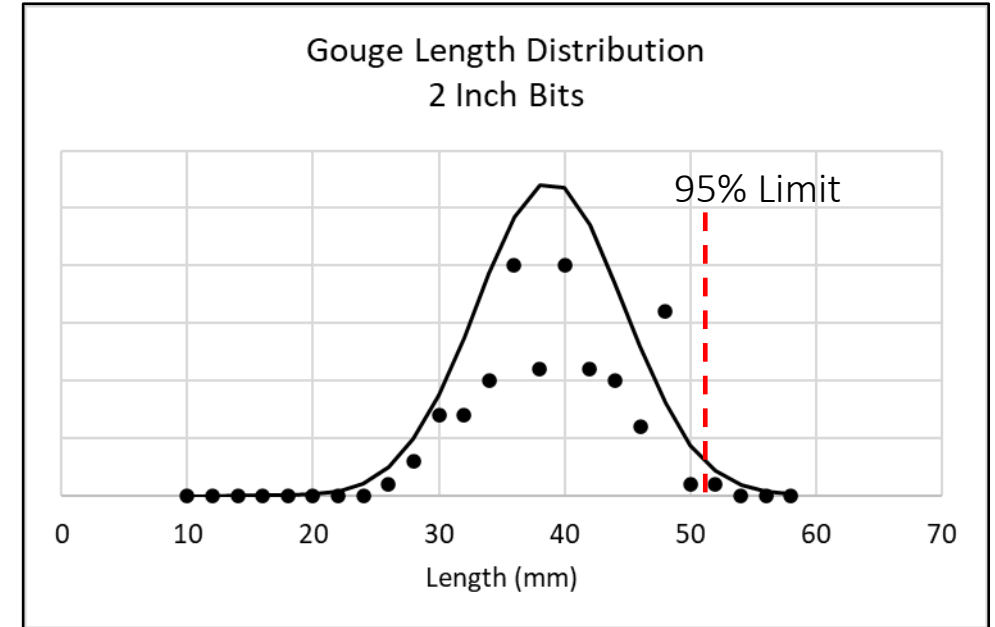
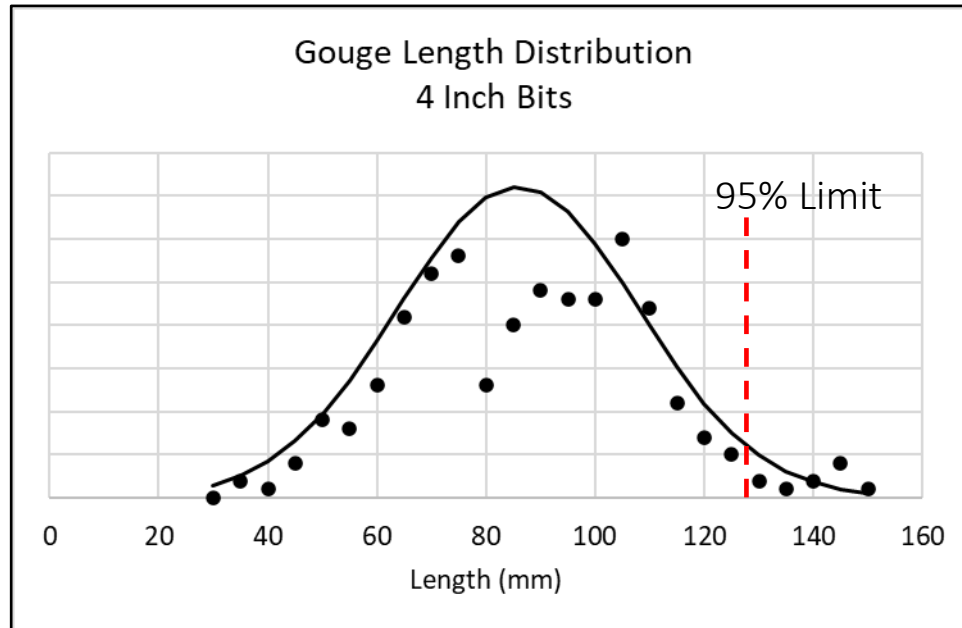
$$\text{Max Gouge Depth} = 1.3 * \ln(\text{PF}) - 9.5$$





HDD Test Results: Gouge Lengths

Gouge length only dependent on bit tip radius





HDD Test Results: Overall Findings

- Observed damage (except Tricone) was series of gouges
 - Max gouge length is dependent on HDD bit tip radius
 - Max gouge depth dependent on number of factors:
 - Lateral restraint i.e. ground restraint, rod diameter
 - HDD bit type
 - Impact position
 - No observed influence from pipe diameter, material grade, coatings, HDD speeds
- Observed damage for Tricone was dimpling
- No associated denting with gouges has been observed
 - However can occur on direct impact with sufficient thrust
- Limitation on capacity of carbide bit tips (approx. 40,000N PF)



Future Fuels CRC is supported through the Australian Government's Cooperative Research Centres Program. We gratefully acknowledge the cash and in-kind support from all our research, government and industry participants.



Australian Government
Department of Industry, Science,
Energy and Resources

AusIndustry
Cooperative Research
Centres Program

The background is an abstract geometric pattern composed of numerous triangles in various shades of blue and teal. The colors range from light, almost white, to dark navy blue. The triangles are of different sizes and are arranged in a way that creates a sense of depth and movement, with some triangles pointing upwards and others downwards.

Thank you for your attention.