DCA-Europe
26th Annual Congress

DCA-Workshop 2022

Accuracy for HDD drillings

Table of Contents

- Power and pipeline network operator requirements
- Types of positional accuracy and what affects it
- How is it controlled?
- What influences the required spacing of the cables?
- Can the required position accuracy decrease by considering conservative assumptions?
- Post-pullback mapping

DCA Thank to all for the very good preparation

Power and pipeline network operator requirements

- Absolute positional accuracy
- Relative to parallel lines
- Homogeneous line routing that enables backfilling of the annulus

network operator requirements

- General: Minimum coverage must be observed for roads, bodies of water or the railway. This is required by the national regulations

- Pipeline operators usually require compliance with the drilling radii or bending radii

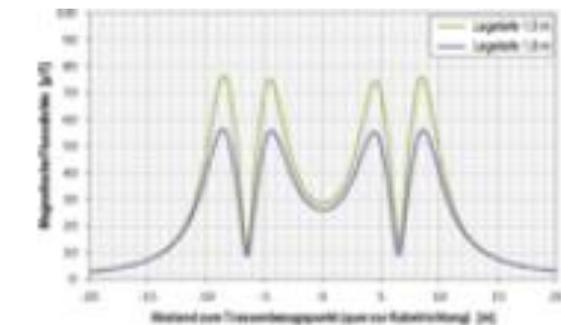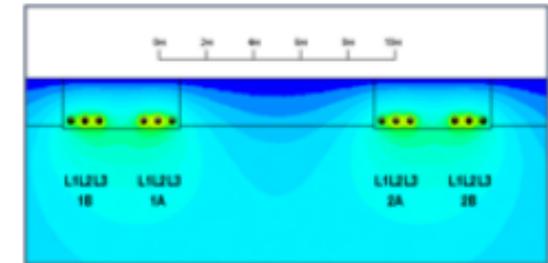# Power network operator requirements

Energy Transition

- to rely heavily on renewable energy (particularly wind, photovoltaics, and hydroelectricity), energy efficiency, and energy demand management

- several thousand kilometres of new power lines
  - Overhead Powerlines or Underground Cables

- Transportation of electricity: AC or DC (Alternating Current or Direct Current)

- New DC projects are now primarily to be planned using underground powerlines

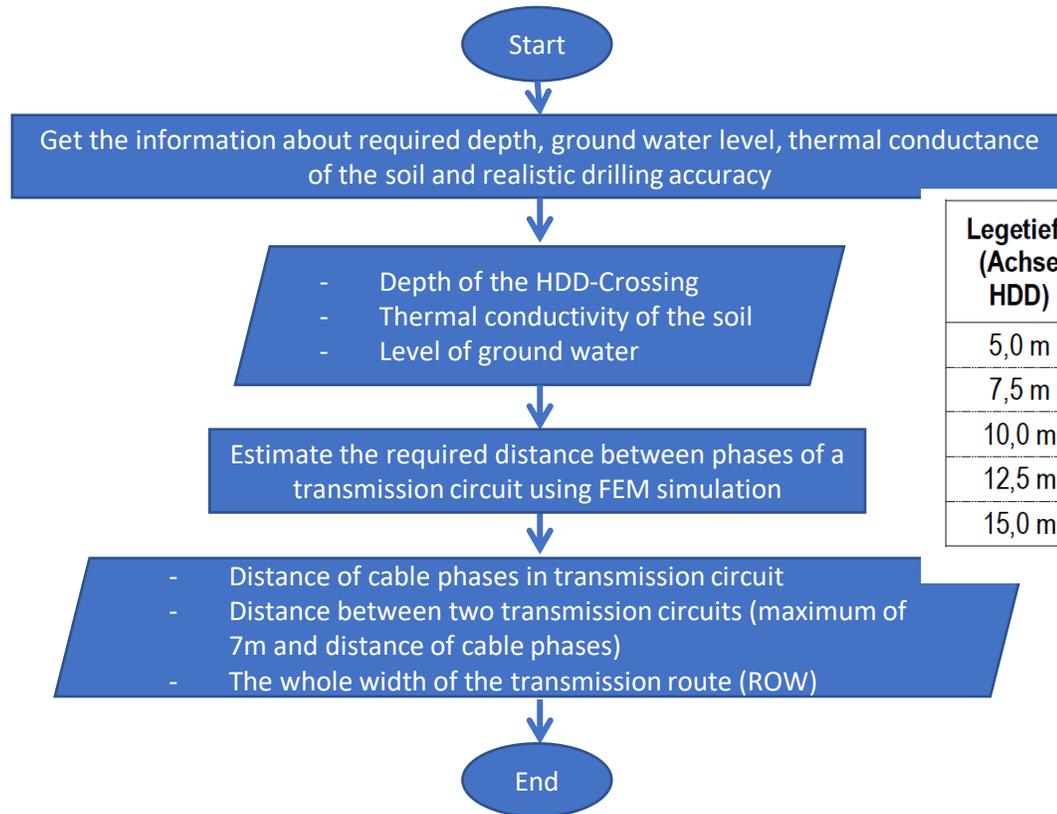- AC projects: Pilot Projects in some sections of the grid
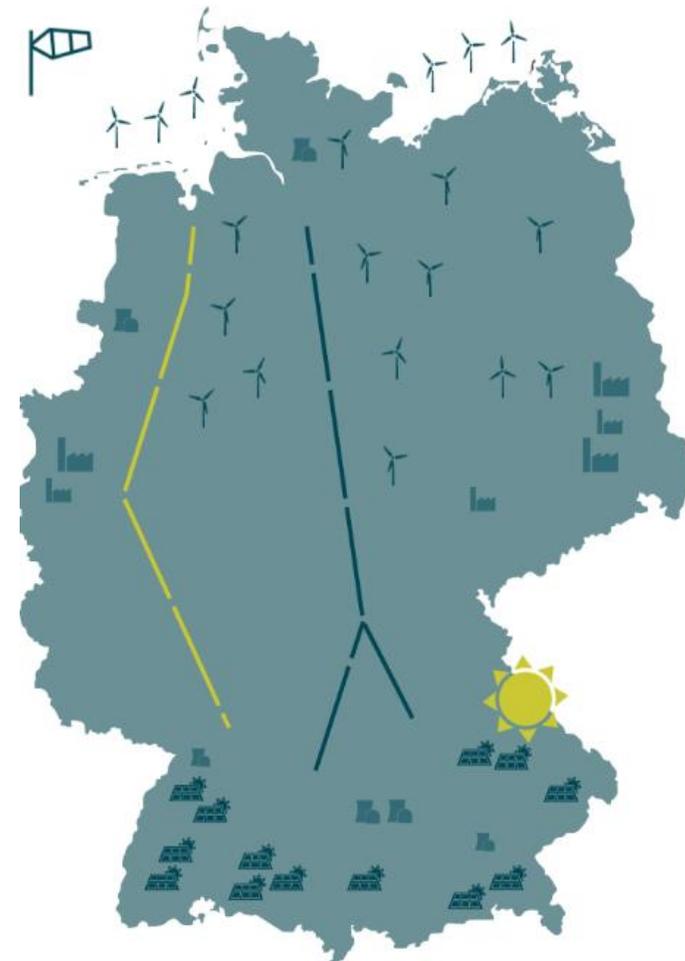
Design and Calculation

- Electrical design
    - Calculation of electric current
    - Calculation of loss for each cable →transmission losses produce heat, which results in cable temperature rise

- Transmission losses → heat, which results in cable temperature rise
    - In open trench: less coverage (1,8m depth) & optimized betting material
    - HDD: distance between the cables has to increase to enable cooling

- Magnetic flux density and restrictions for immissions
    - For HDD drilling to be considered at entry and exit sections (depths up to 3m)

- Demand for minimized route widths as a permit requirement (bundling idea)

| Kabel		1B/L1	1B/L2	1B/L3	1A/L1	1A/L2	1A/L3	2A/L1	2A/L2	2A/L3	2B/L1	2B/L2	2B/L3
Leiterstrom	[A]	1536	1546	1631	1616	1605	1519	1546	1546	1640	1606	1604	1510
Schirmstrom	[A]	105,3	40,9	52,7	34,3	71,2	45,8	73,9	6,9	53,3	14,8	89,7	81,8
Max.Tempe- ratur	Rohr [°C]	57,6	64,8	64,8	65,3	67,0	58,4	58,7	65,5	65,5	64,5	66,2	57,1
	Leiter	78,8	86,1	88,3	88,4	89,9	79,1	80,1	86,9	89,3	87,3	89,2	77,7
Verluste pro Kabel	[W/m]	35,1	35,5	38,9	38,2	38,5	33,7	35,1	35,4	39,4	37,6	38,6	33,7

Power network operator requirements

Thermal Design

```
Start
  ↓
Get the information about required depth, ground water level, thermal conductance
of the soil and realistic drilling accuracy
  ↓
  -  Depth of the HDD-Crossing
  -  Thermal conductivity of the soil
  -  Level of ground water
  ↓
Estimate the required distance between phases of a
transmission circuit using FEM simulation
  ↓
  -  Distance of cable phases in transmission circuit
  -  Distance between two transmission circuits (maximum of
     7m and distance of cable phases)
  -  The whole width of the transmission route (ROW)
  ↓
End
```

Legetiefe (Achse HDD)	Temperatur Erdboden	Spezifischer Wärmewiderstand Erdboden (H > 2 m) feucht (Km/W) / trocken (Km/W)								
		0,6 / 0,6	0,7 / 1,0	0,7 / 1,2	0,8 / 1,2	0,7 / 2,0	0,8 / 1,5	0,9 / 1,2	1,0 / 1,2	1,0 / 1,5
5,0 m	13,3 °C	1,5 m	3,4 m	4,1 m	4,7 m	6,2 m	5,9 m	5,2 m	5,8 m	7,7 m
7,5 m	11,4 °C	1,8 m	4,7 m	5,9 m	7,0 m	9,7 m	9,1 m	8,0 m	9,2 m	12,8 m
10,0 m	10,5 °C	2,3 m	6,4 m	8,0 m	9,7 m	13,8 m	12,9 m	11,4 m	13,2 m	19,6 m
12,5 m	10,3 °C	2,9 m	8,3 m	10,6 m	13,1 m	19,0 m	17,8 m	15,7 m	18,6 m	29,3 m
15,0 m	10,0 °C	3,5 m	10,4 m	13,3 m	16,6 m	24,8 m	23,1 m	20,2 m	24,3 m	41,3 m

Power network operator requirements

High Accuracy for AC-Cable matters

Deviation from working corridor	Cosequences
Lateral: +/-0,5 m	Revise thermal design -->further measure required or plug drilled hole and drill a new hole
Vertical: +0,5m	
Vertical: -0,5m	No Consequences
Vertical & lateral: <0,5m	Considered in design

Example 110 kV Cable:
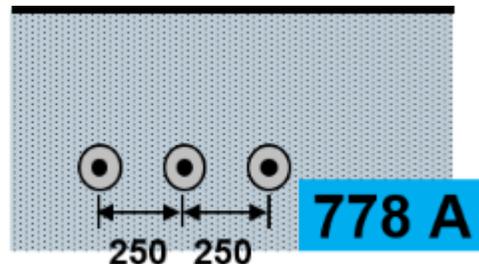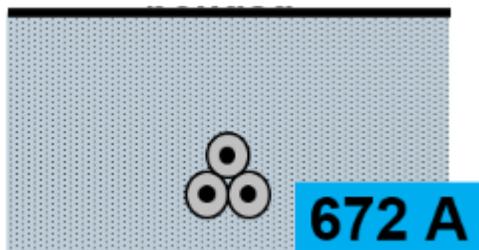
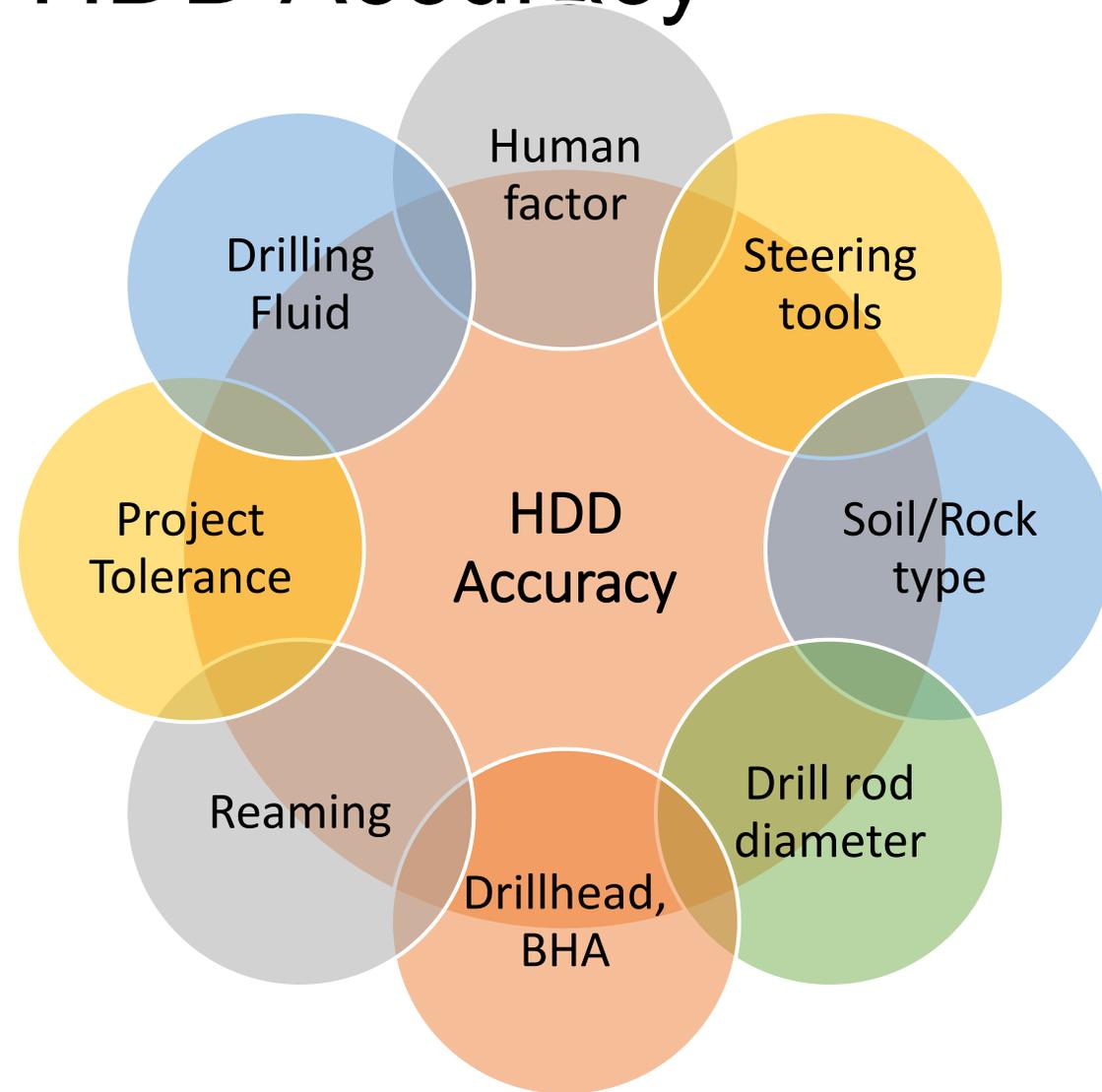# Power network operator requirements

High Accuracy for DC-Cable is important
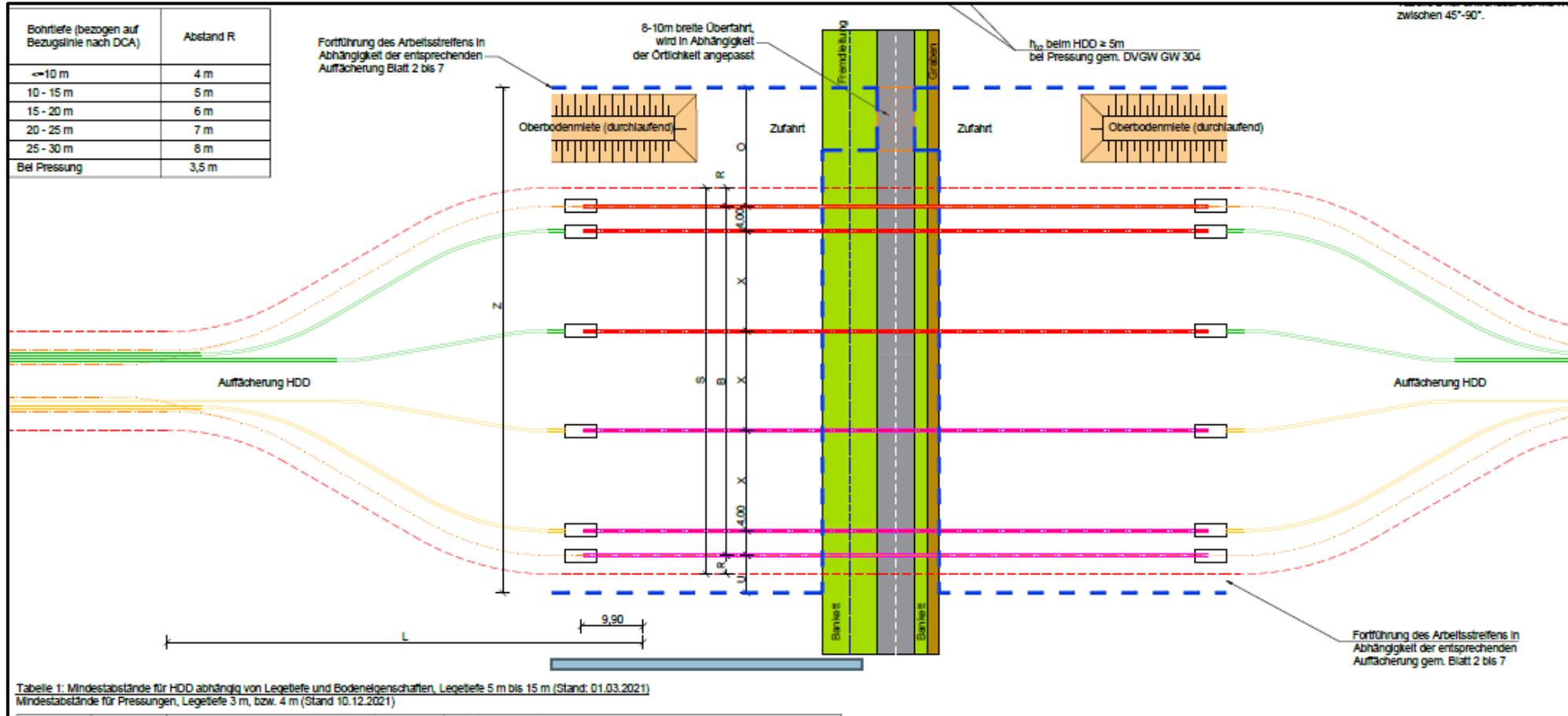
Types of accuracy

- Target
- bending radius - relative position
- distance drilling to drilling - absolute position

Influence of HDD Accuracy
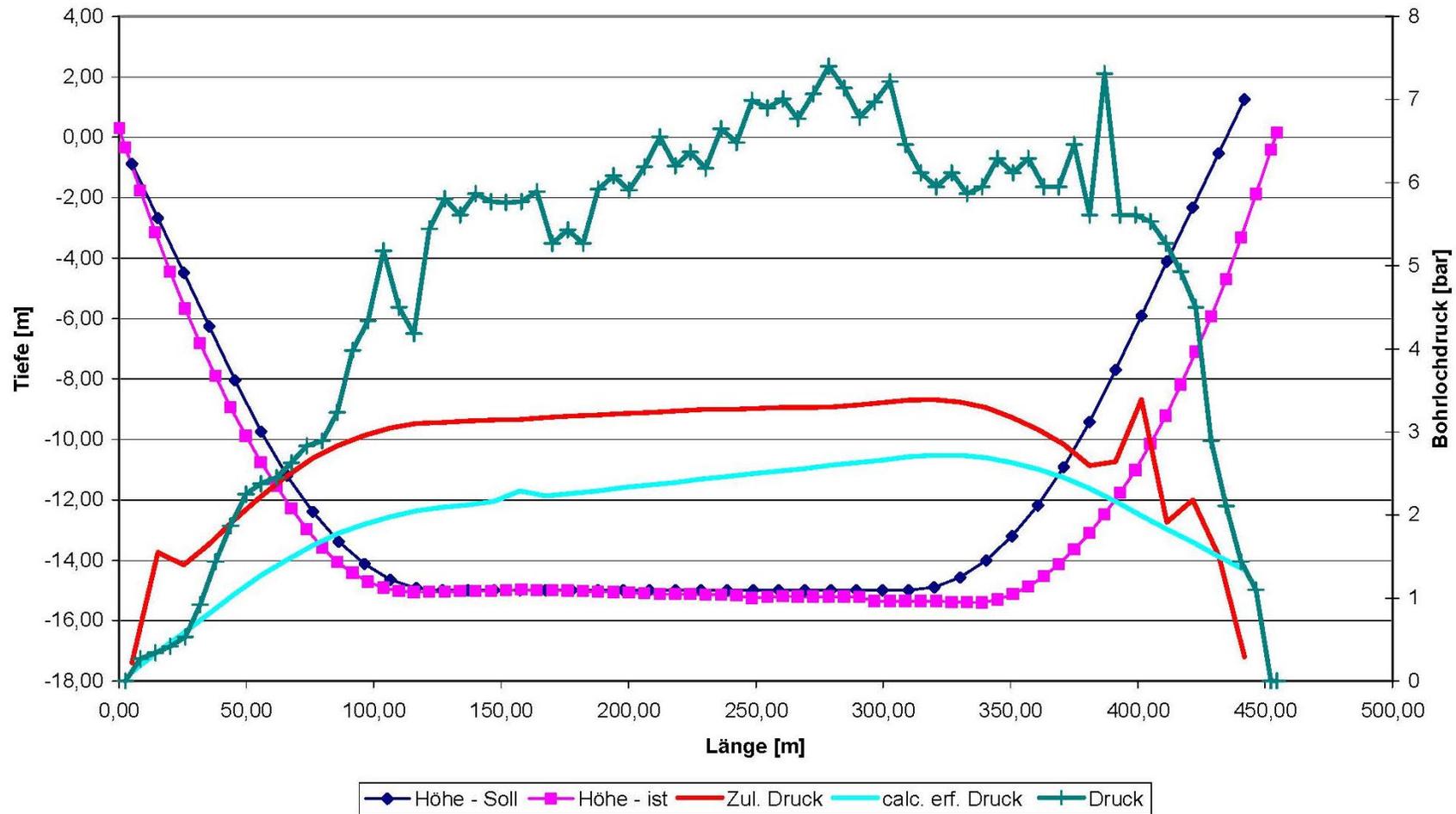
Target

example - bending radius - relative position

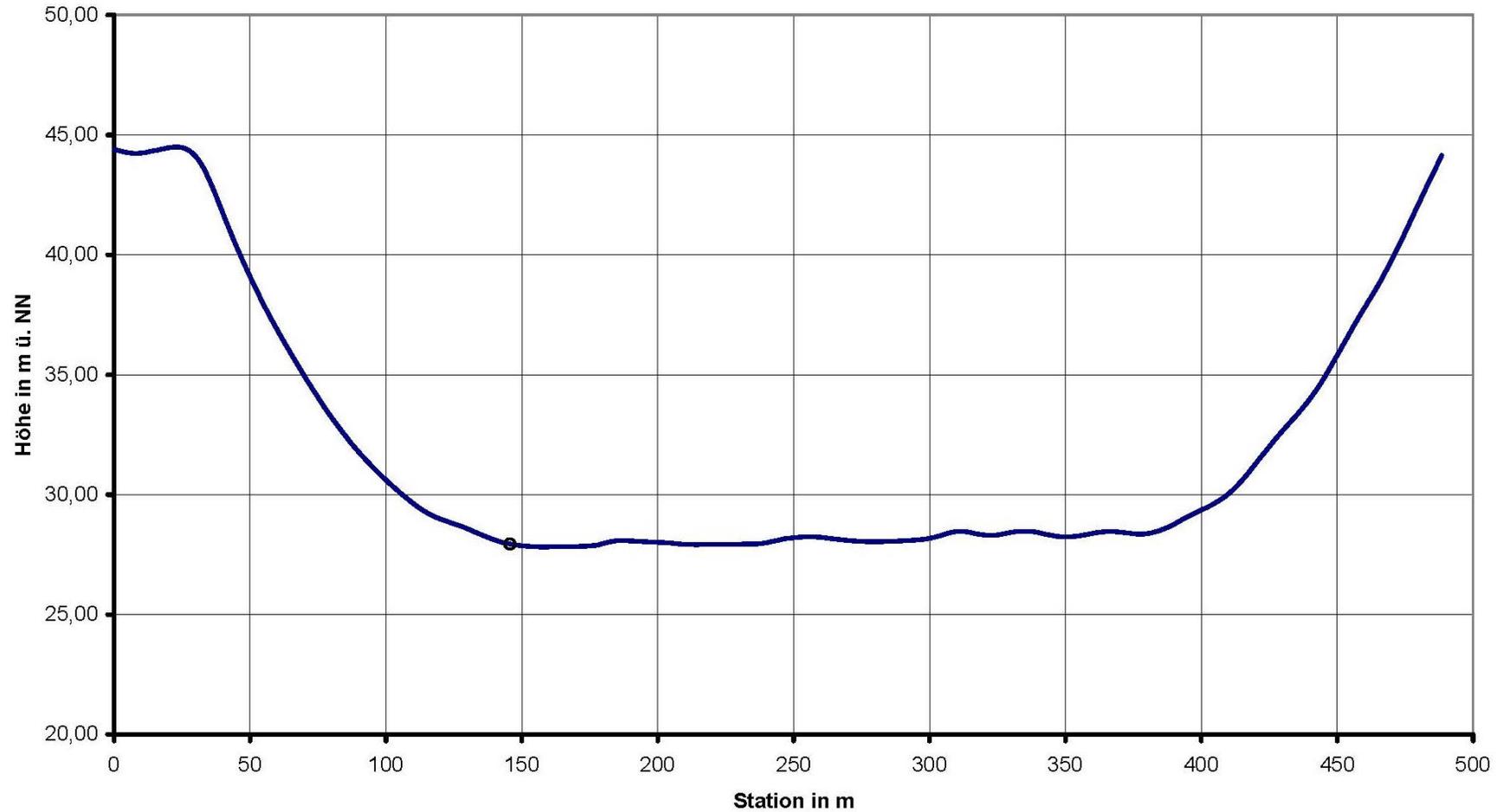# 2 HDD – DN 400 – DN 100 – L=450 m
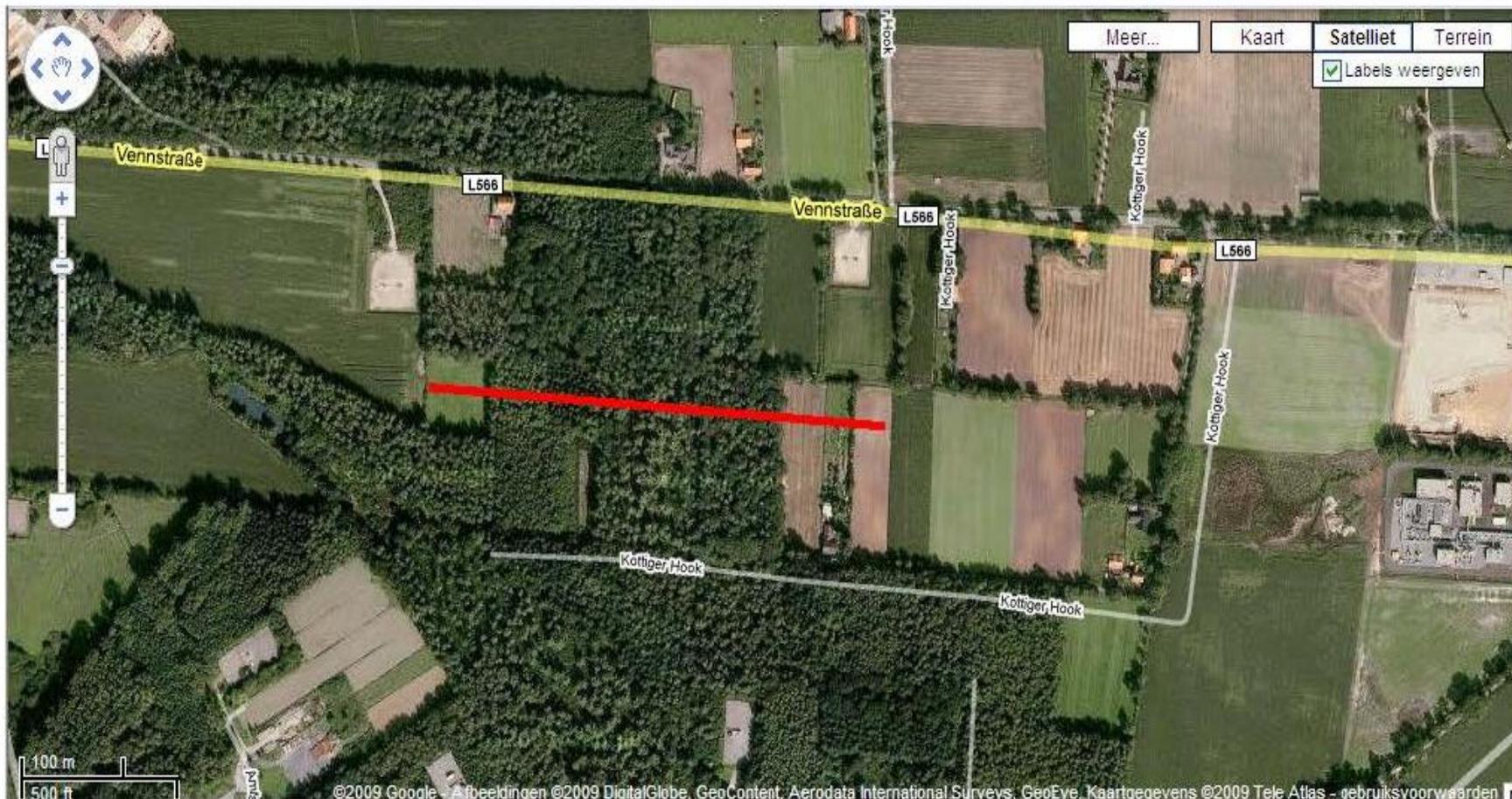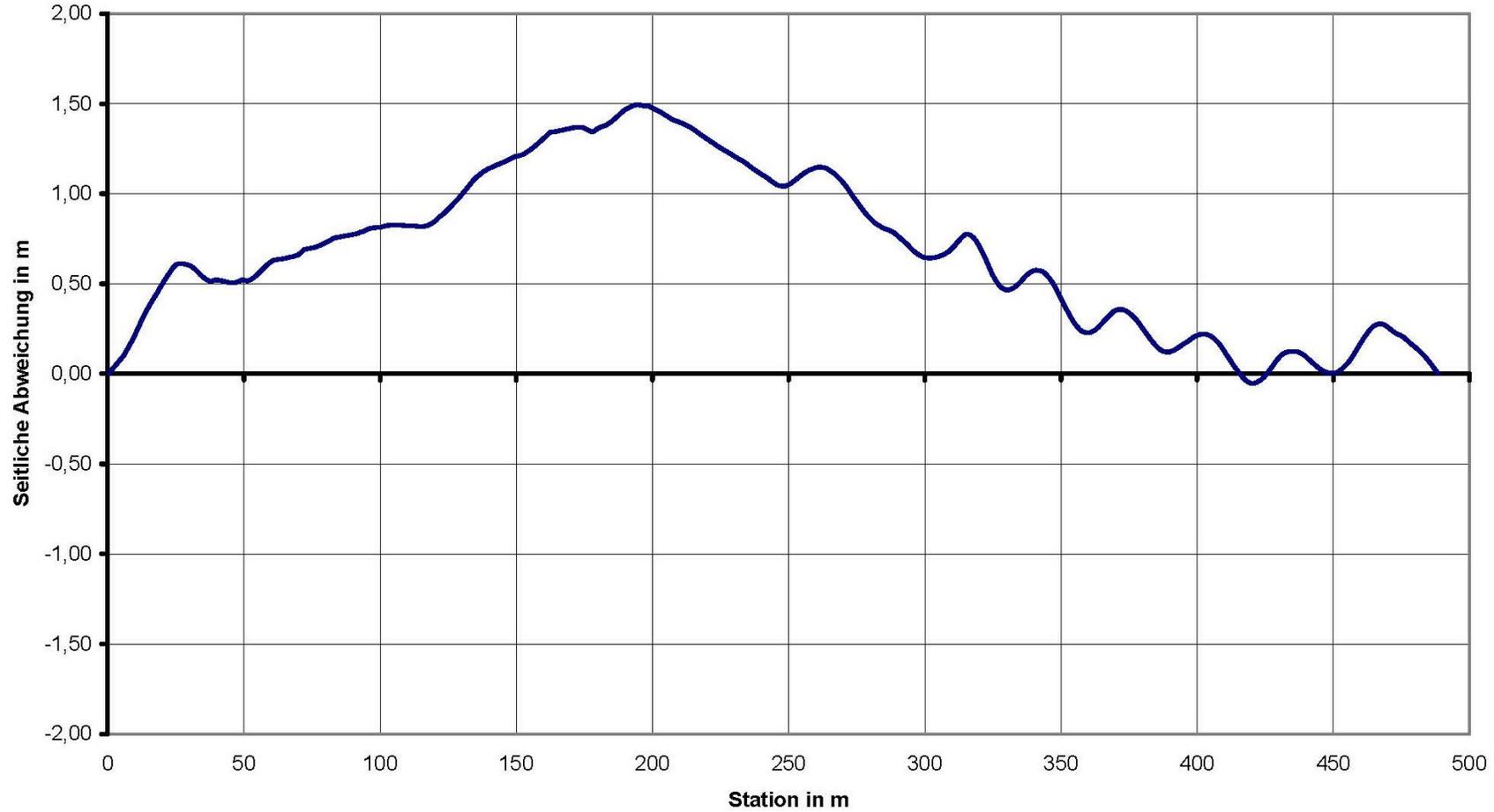
Profil and mud pressure
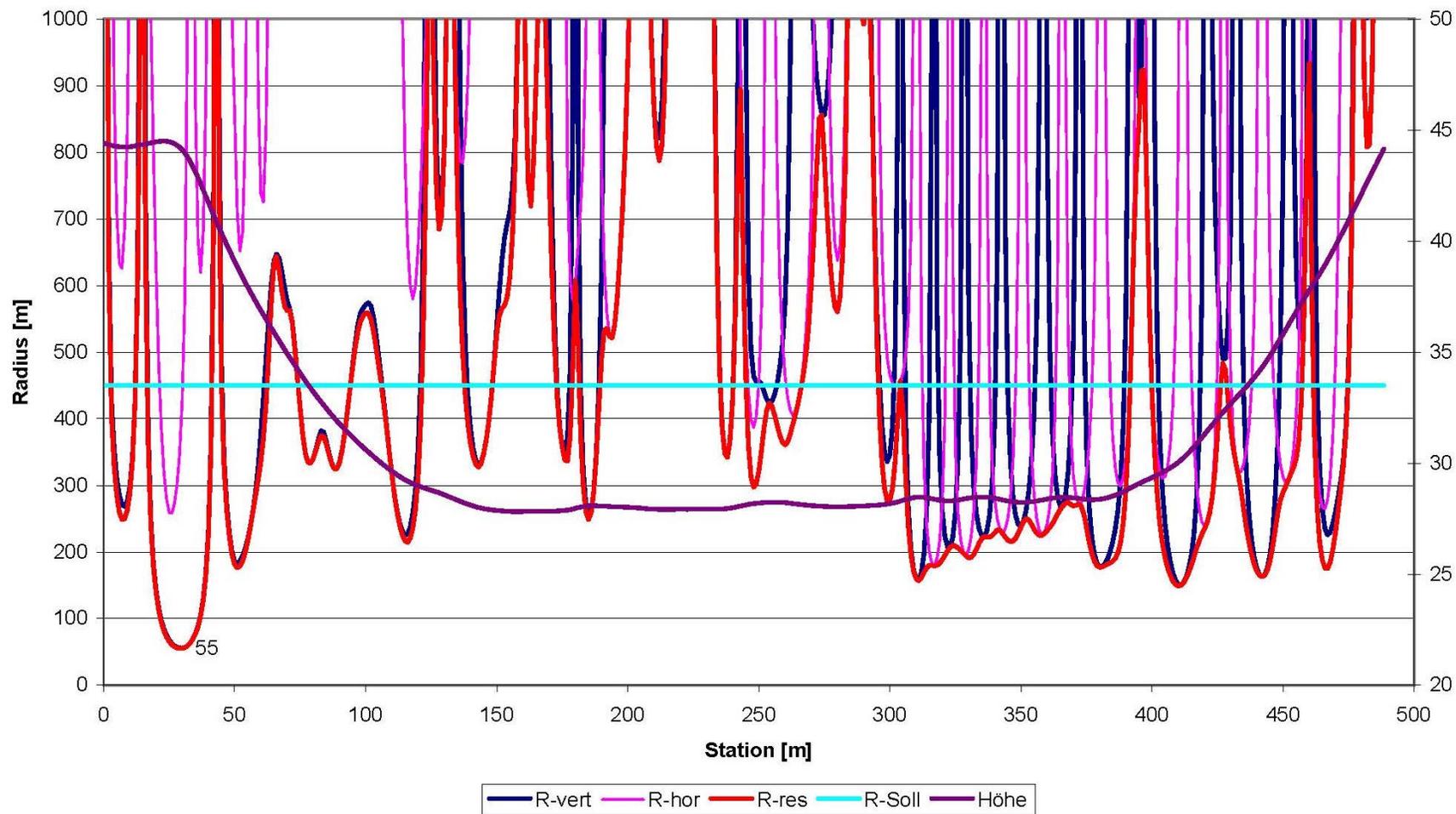
Measurement of the product line – profil

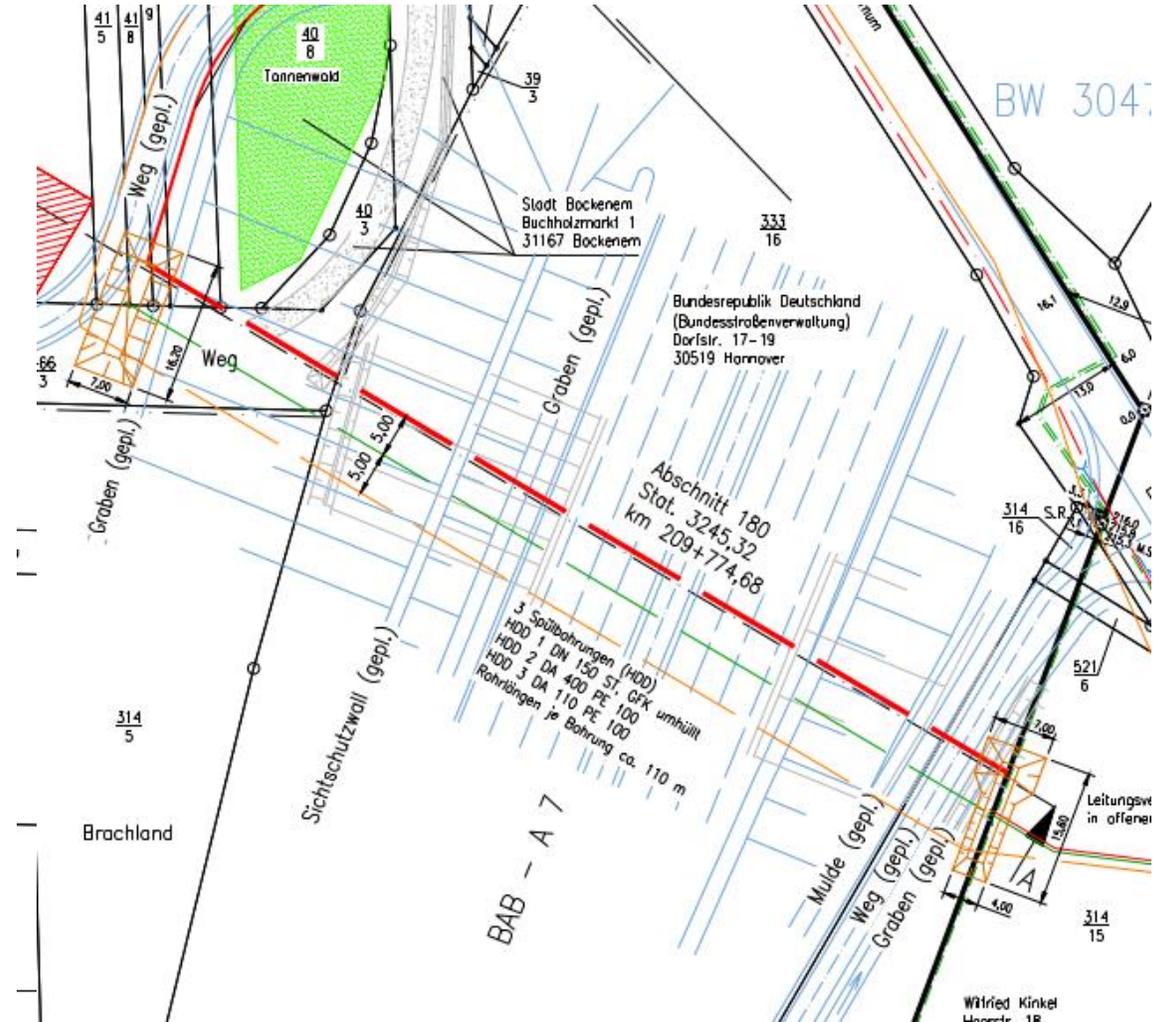# Measurement of product line - Horizontal plane

Product line allowance – bending radii

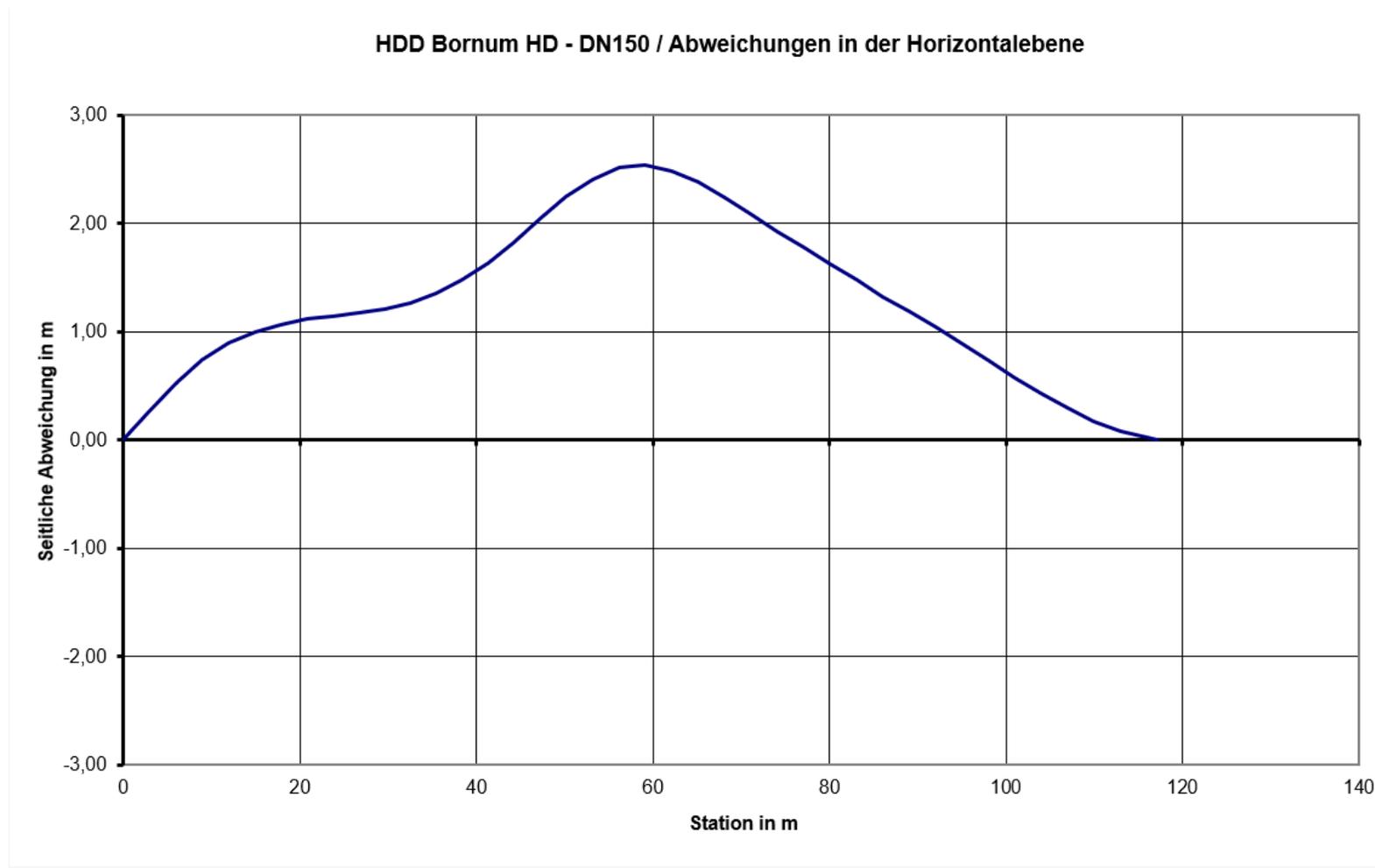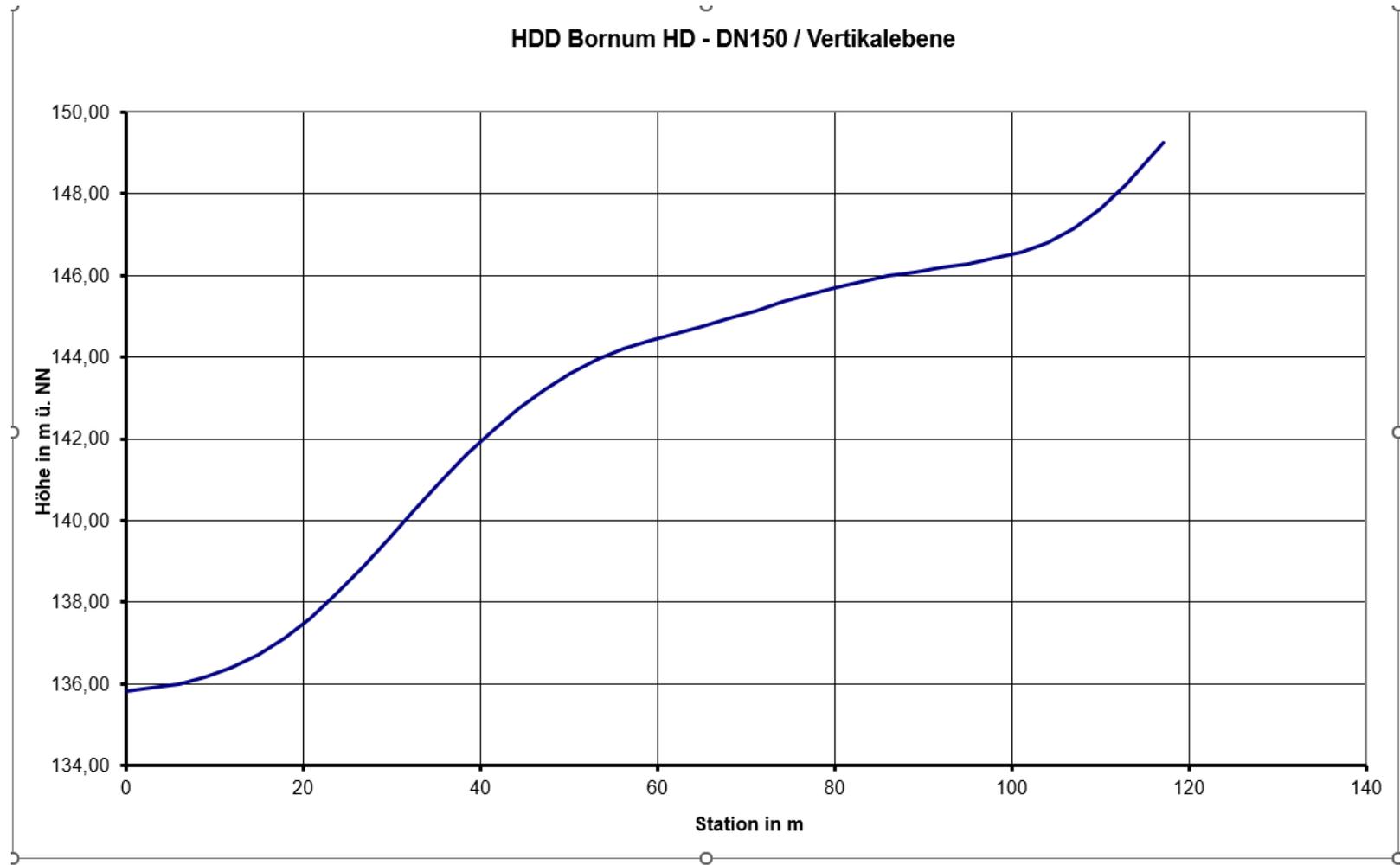**DCA** example - distance drilling to drilling - absolute position

Crossing Highway

Profil

Product-pipe - deviation from the drilling axis

HDD Bornum HD - DN150 / Abweichungen in der Horizontalebene

Product-pipe - Profil

HDD Bornum HD - DN150 / Vertikalebene
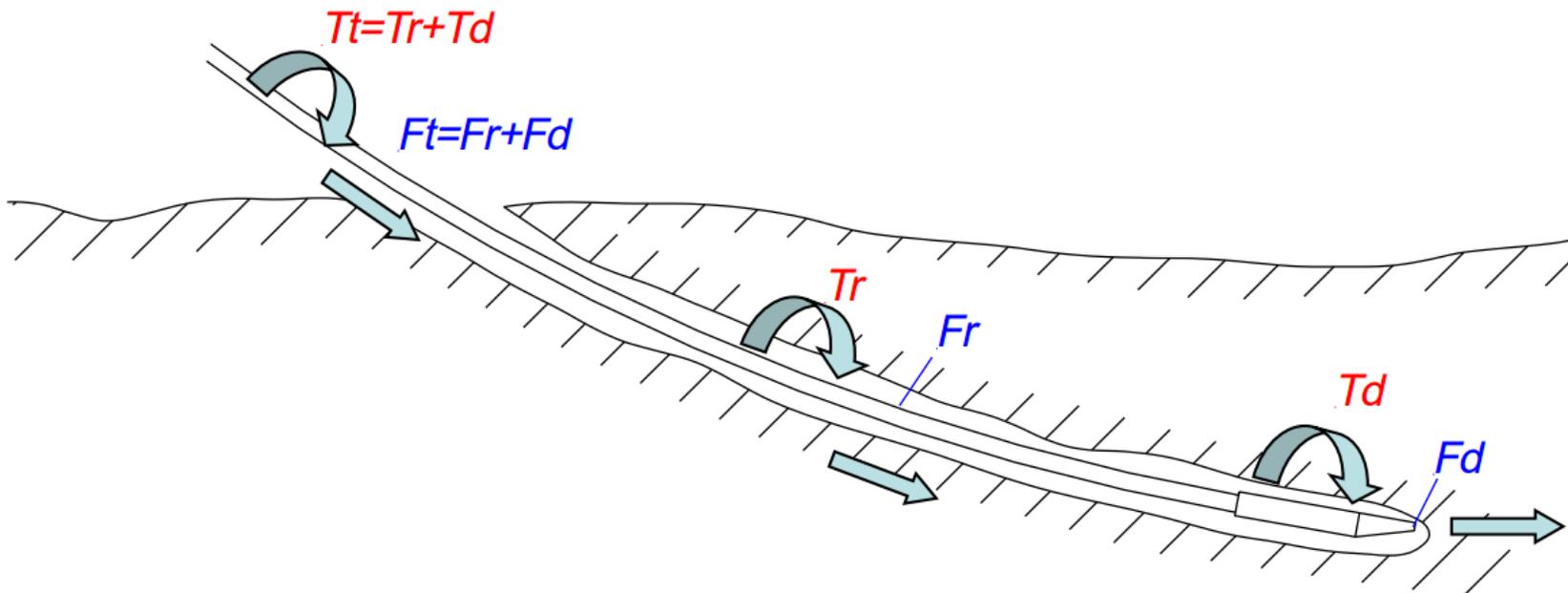
Accuracy of pilot drilling

The location of the drill-head depends upon:

- The interaction between the drill-head and the soil
    - Type of drill-head
    - Type of soil or rock
    - Flow of drilling fluid and interaction with the soil
        - Detachment and displacement of soil particles/cuttings
    - Movement of the drill-head by the driller
        - Movement depends in turn upon the measurement of the (expected) location of the drill-head
        - Movement depends upon the stifness of the drill string in relation to the stiffness of the surrounding soil or rock
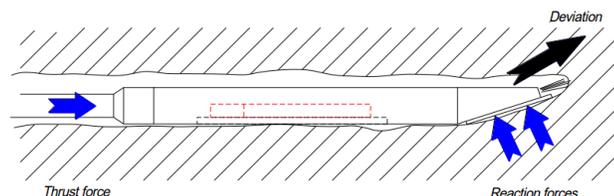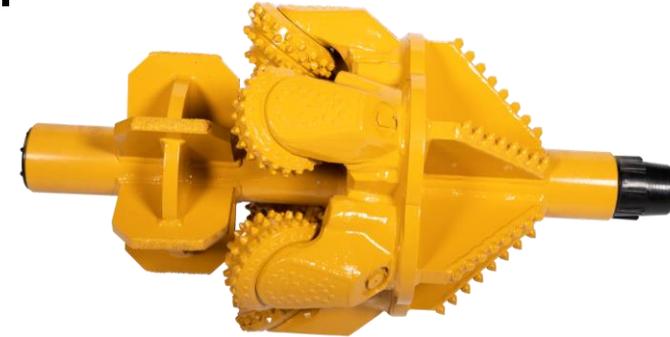
Forces during pilot

- *Forces during drilling*
- *Forces during steering*

  - *Thrust force and torque for the drillhead to compact/cut the soil (Td & Fd)*
  - *Thrust force and torque to overcome drag in the hole (Tr & Fr)*

$Tt=Tr+Td$

$Ft=Fr+Fd$

Tr

Fr

Td

Fd

Accuracy of reaming

- The shape and location of the borehole and the drilling line depend upon:
- The interaction between the reamer and and the soil
  - Type of reamer
    - Weight
    - Nozzle positions
    - Position of the teeth
  - Type of soil
  - Flow of drilling fluid and interaction with the soil
    - Detachment and displacement of soil particles
  - Pulling velocity, rotation velocity and pulling force applied by the driller
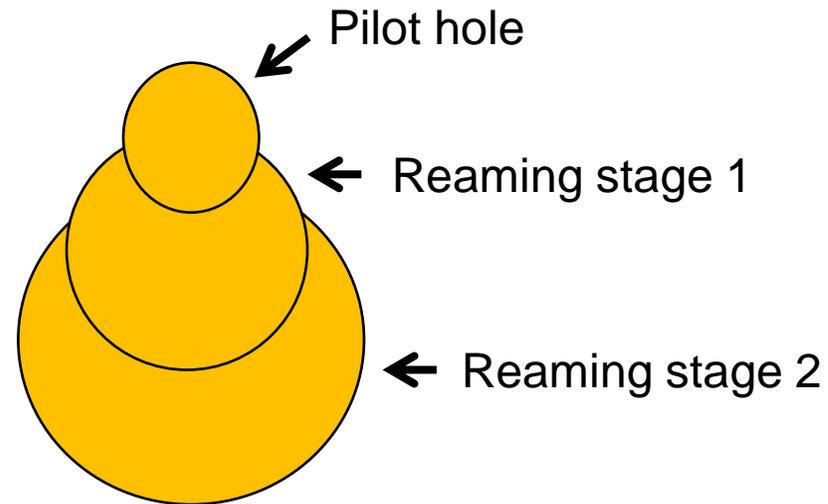
Forces during reaming

- *Forces during reaming*

    - *Thrust force and torque for the reamer to compact/cut the soil (Td & Fd)*
    - *Thrust force and torque to overcome drag in the hole (Tr & Fr)*
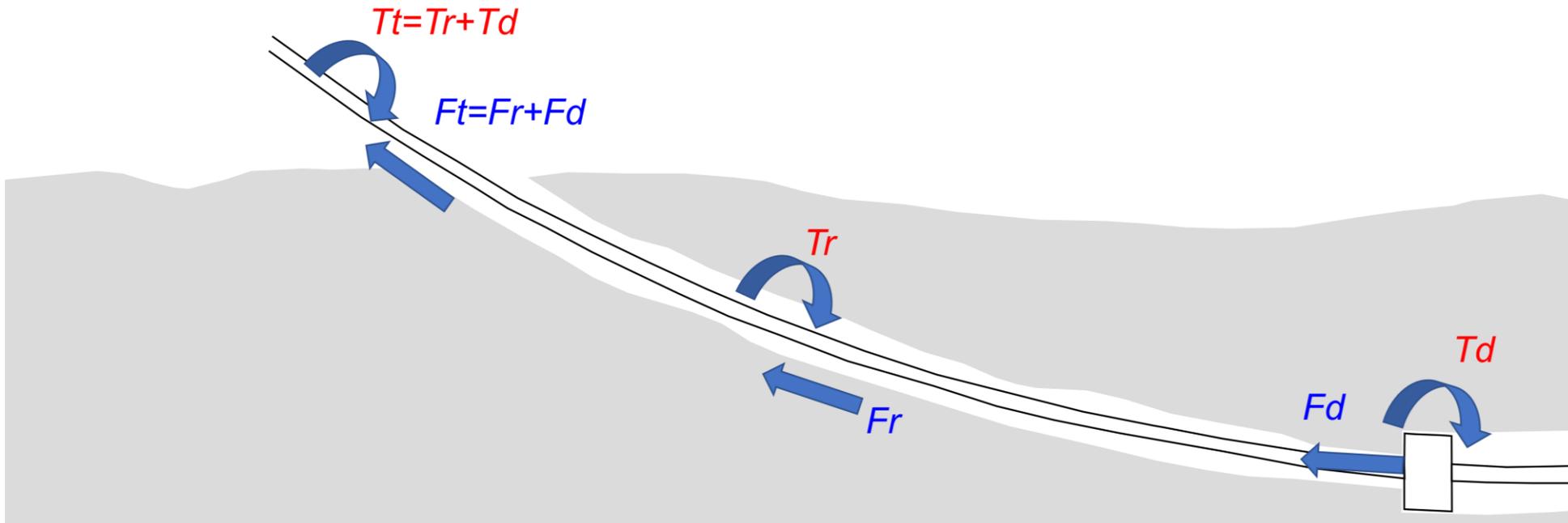
Shape of the borehole after reaming

- Axial shape of the borehole (drilling line)
- Centralisation
- Tangential shape of the borehole

Pilot hole

Reaming stage 1

Reaming stage 2

Example: Loose packed sandy soils and heavy reamers

Pull back of the product pipe

Interaction between the drill-string, the product pipe and the soil depends upon the stiffness of the drill-string and pipe and weight of the pipe in relation to the stiffness of the surrounding soil.
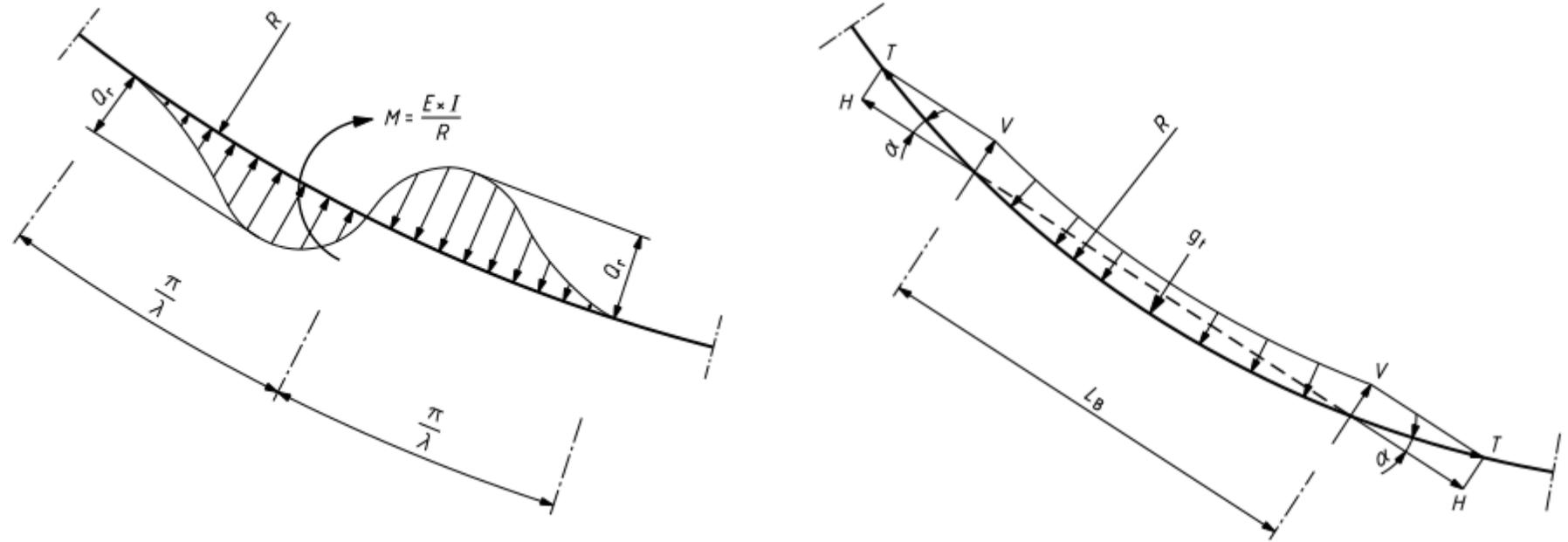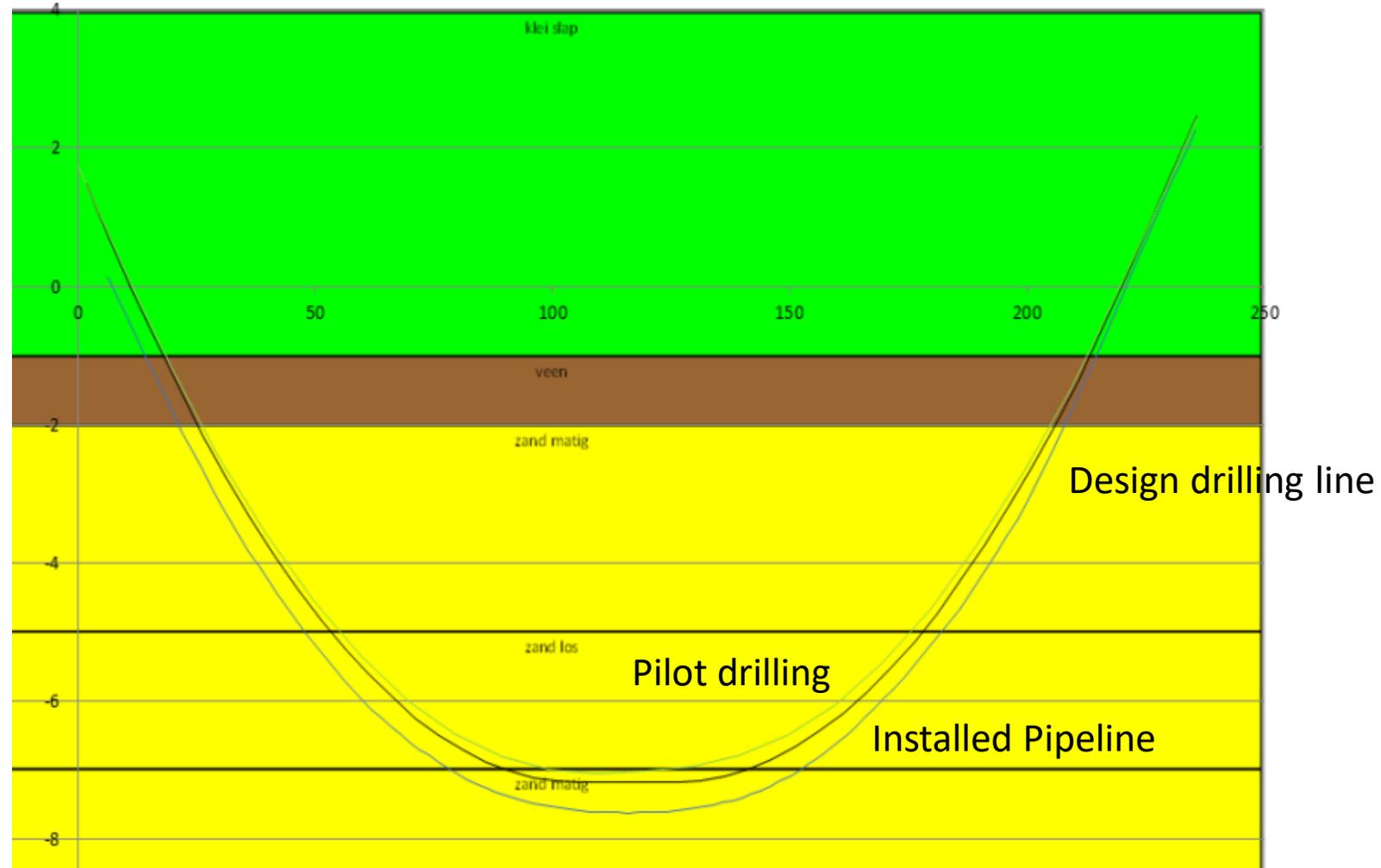
Top view of installed pipeline

- PE pipeline (measured)
- Pilot drilling line (measured)
- Design drilling line

Design drilling line

Pilot drilling

Installed Pipeline
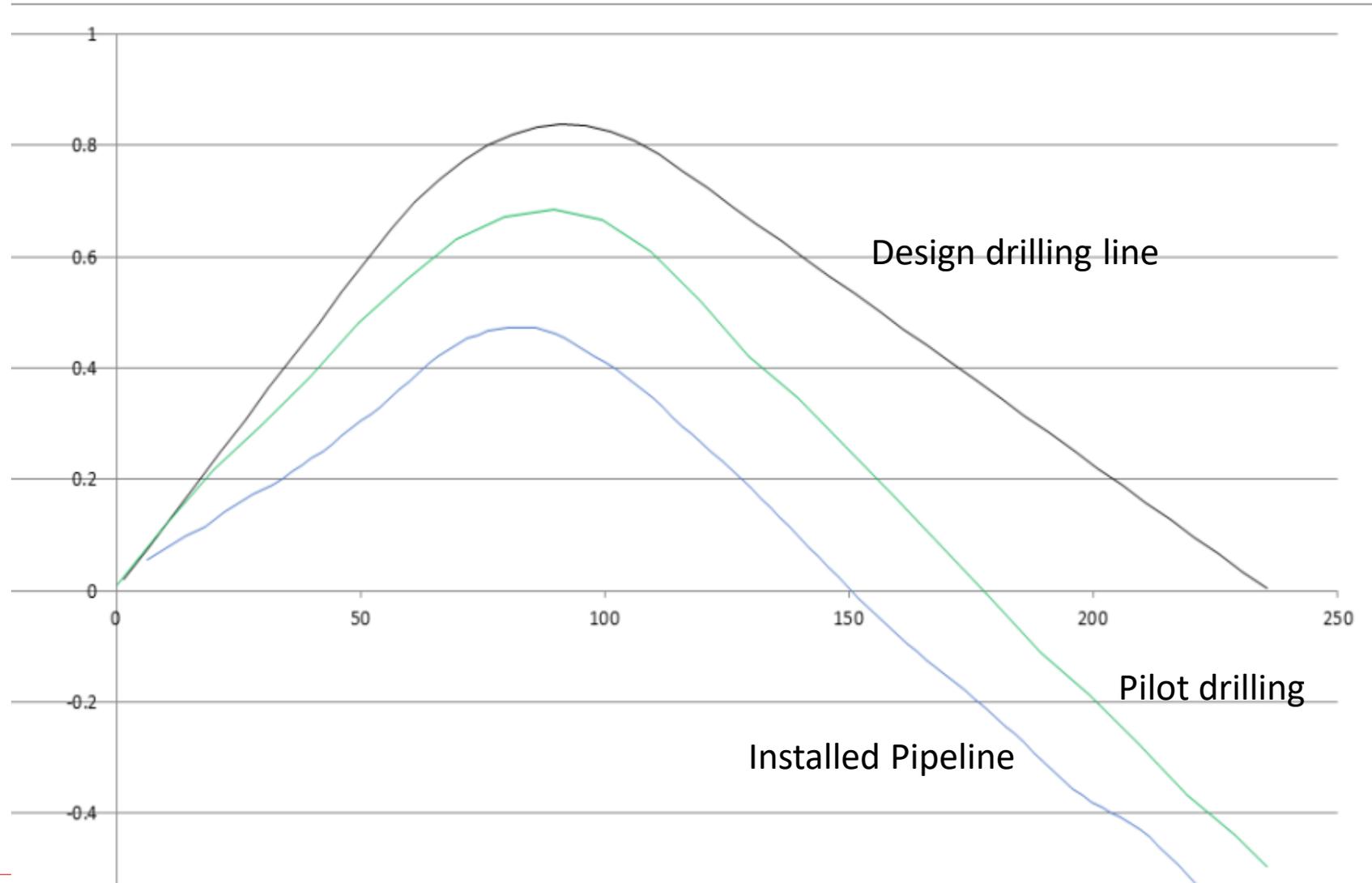
Longitudinal cross section of drilling line

- PE pipeline (measured)
- Pilot drilling line (measured)
- Design drilling line

How is it controlled?

- Locating, Procedure, Accuracy
- Directional control

- *What affects directional control?*
- *Driller and the DD - human-factor*
- *Limits of each Steering tool*
- *Soil*
- *Drill rod diameter*
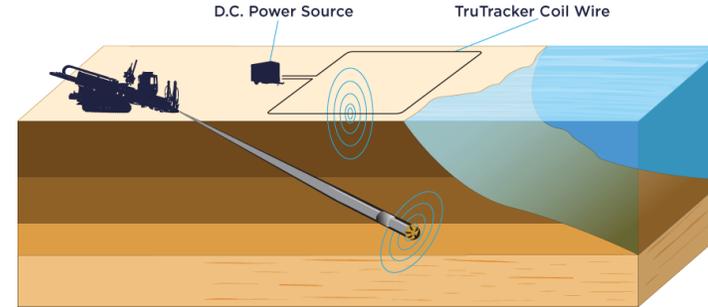- *Tools: Drill head - Reamer, etc*

definition

- Accuracy - Deviation
- steering tool

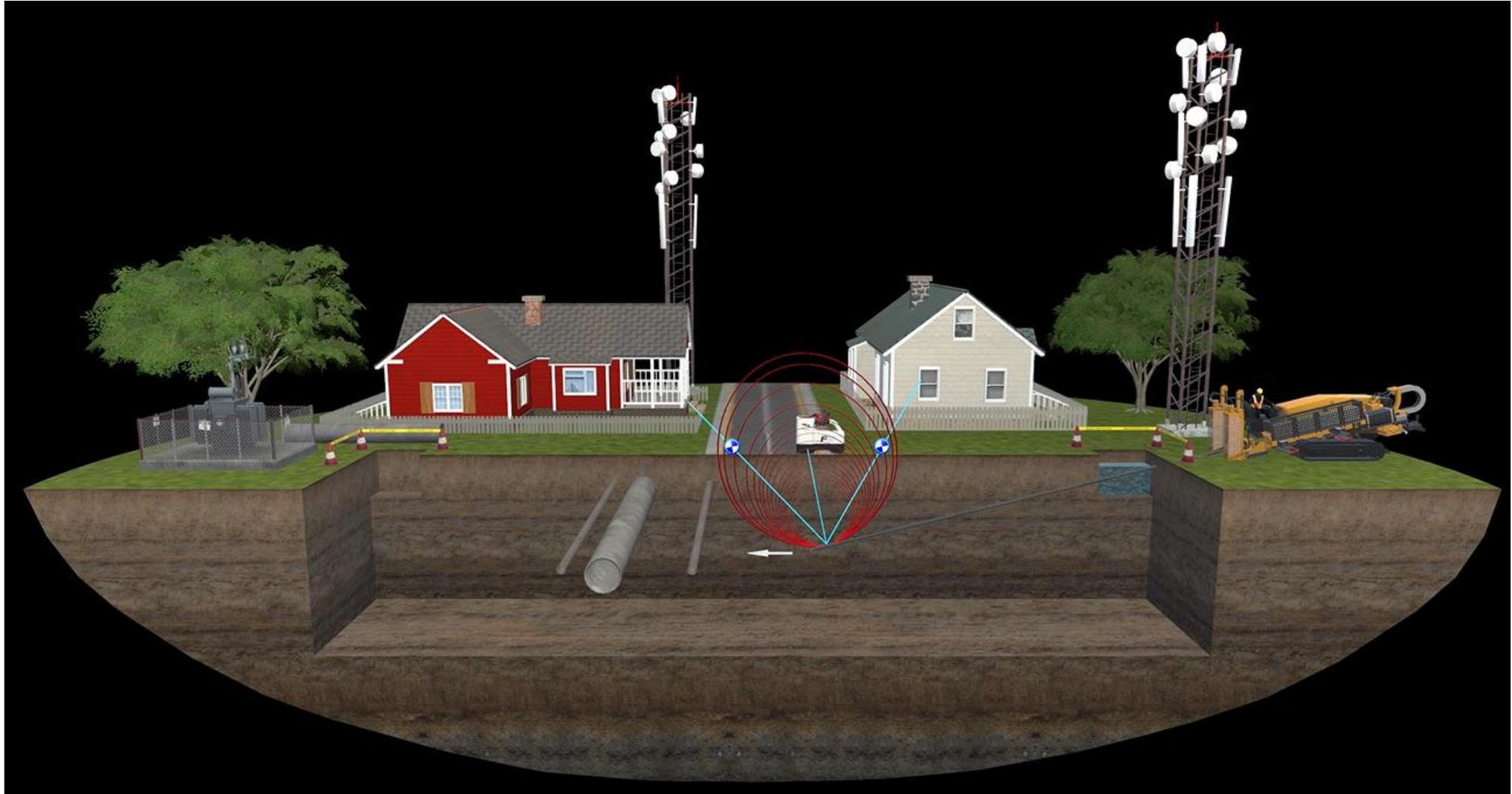# Common HDD Guidance Methods

Walkover Locator

Magnetic Tracking
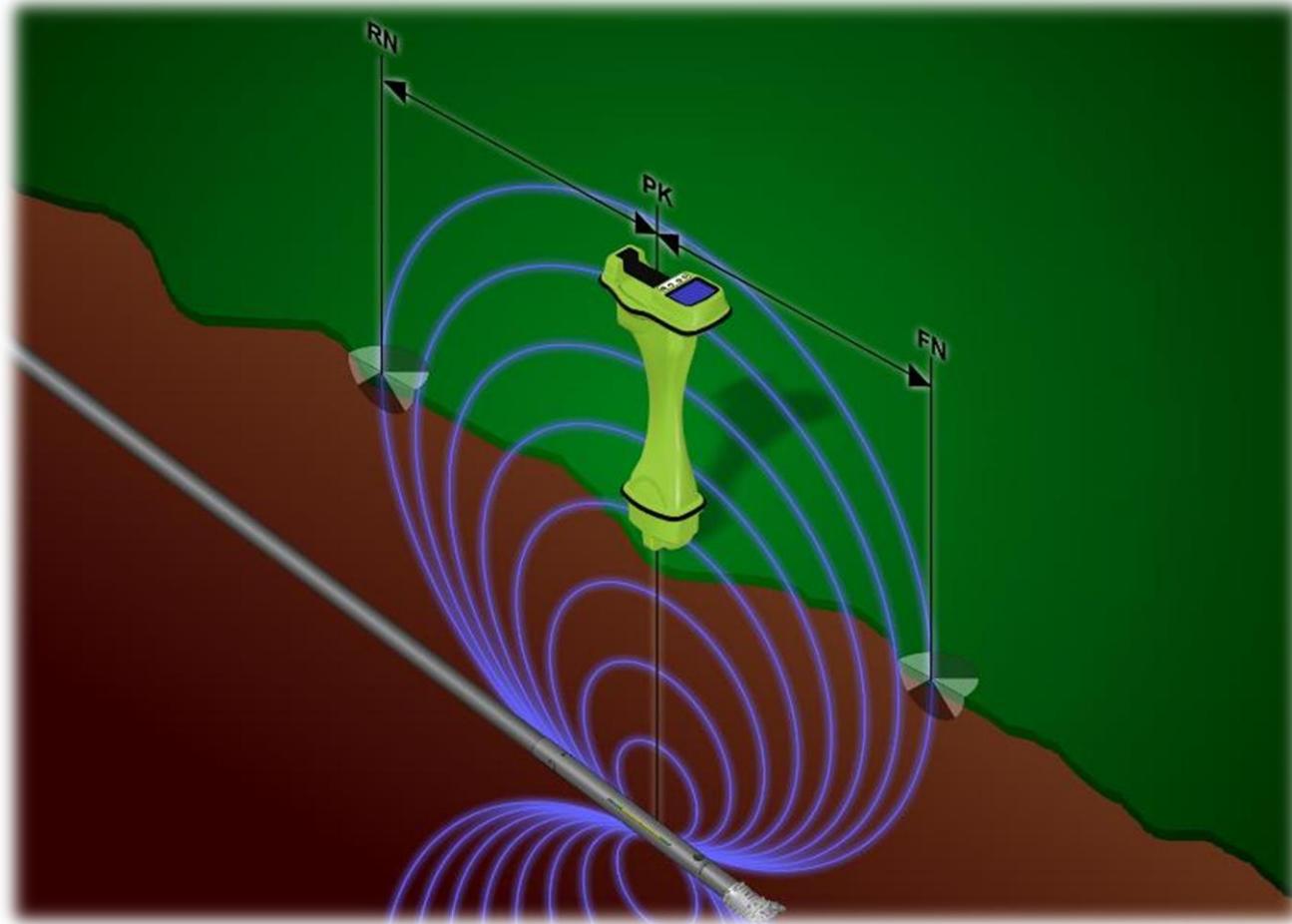

Gyroscopic Surveys

Combination Tracking & Survey

Principle Walk over

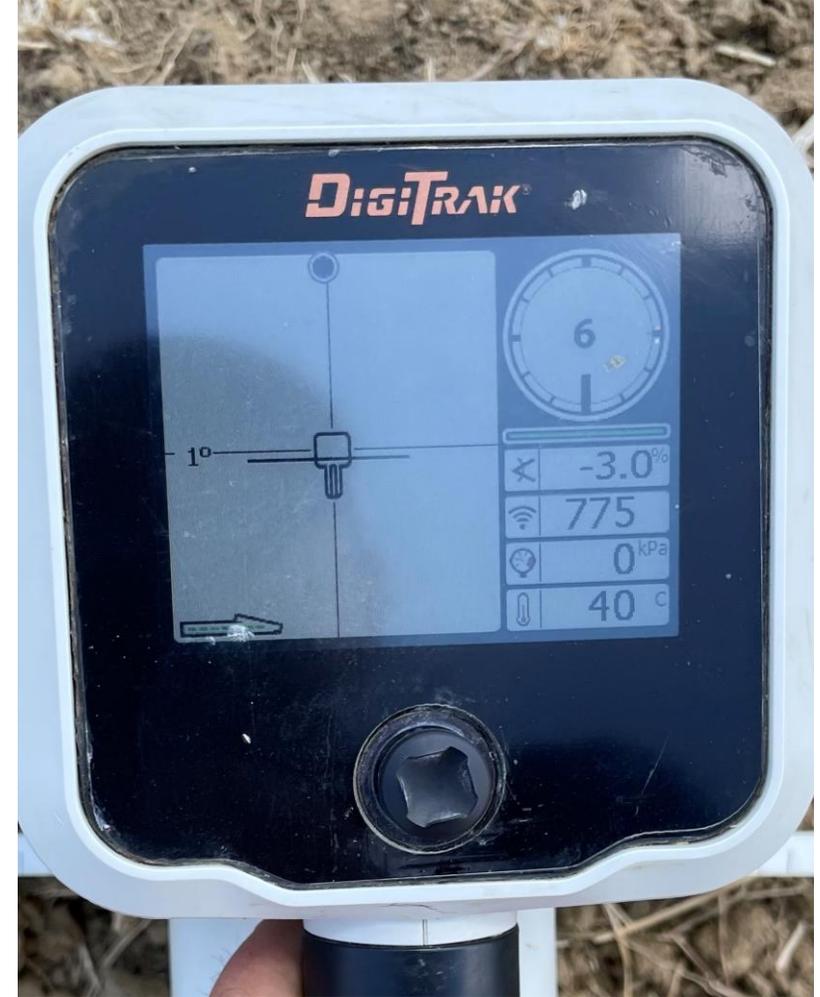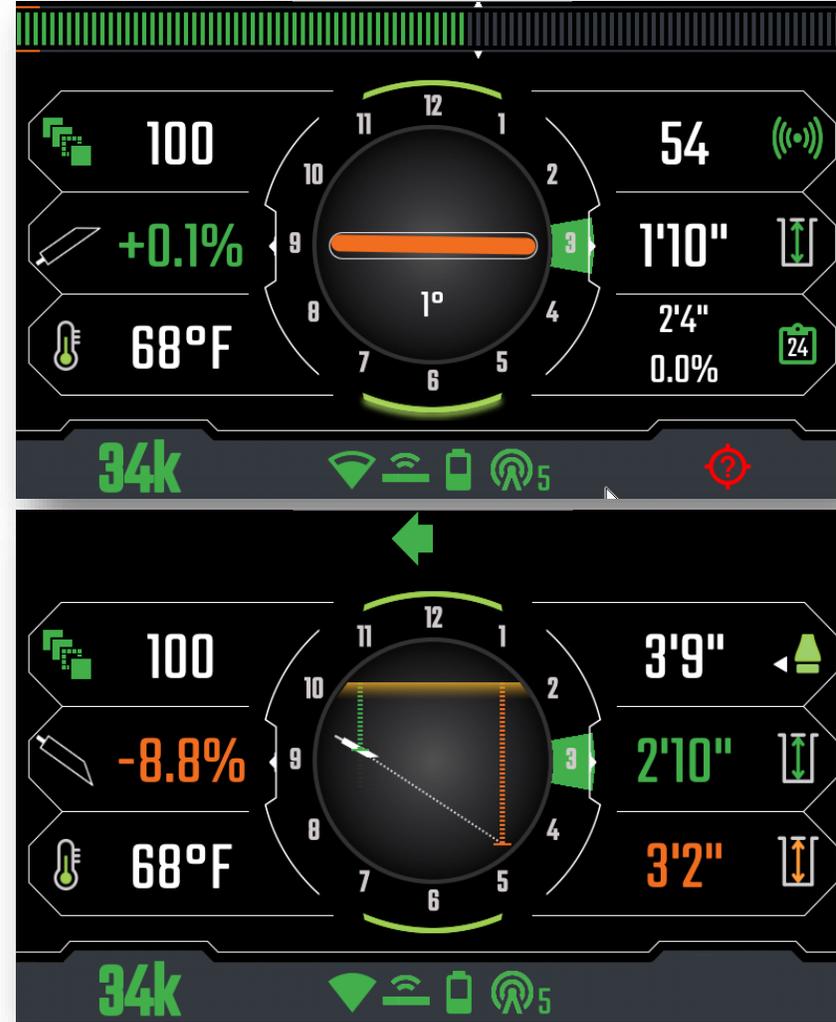# Principle Walk over

Projects.

Projects.

Magnetic Tracking
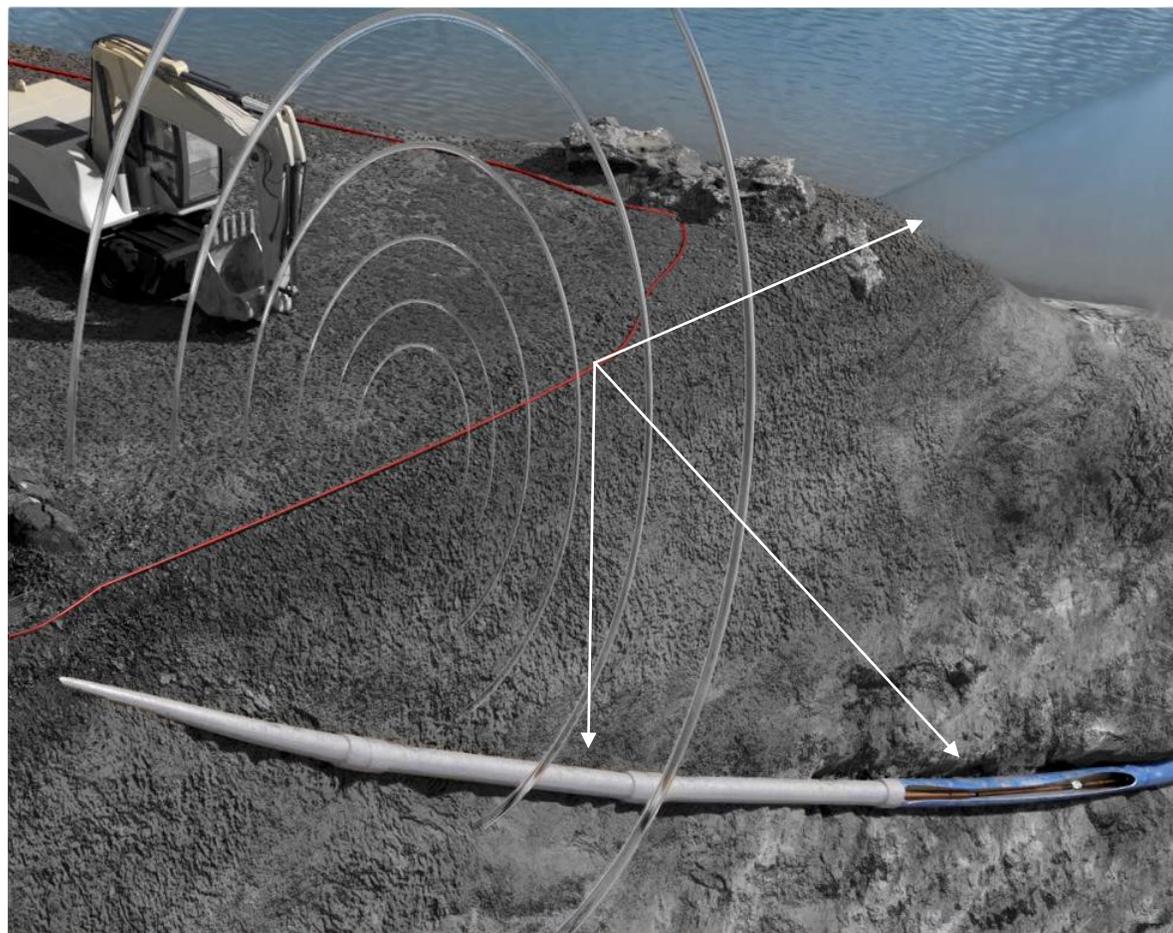
- Magnetic source is surveyed into x,y,z coordinates

- Measures directly from sensor to source at every station

- Each measurement is independent

- No accumulation of survey error

Magnetic Tracking: Parallel Bore System

10m depth 500m length

28cm pilot bore

50cm installed product

2m bore spacing

50cm installed product
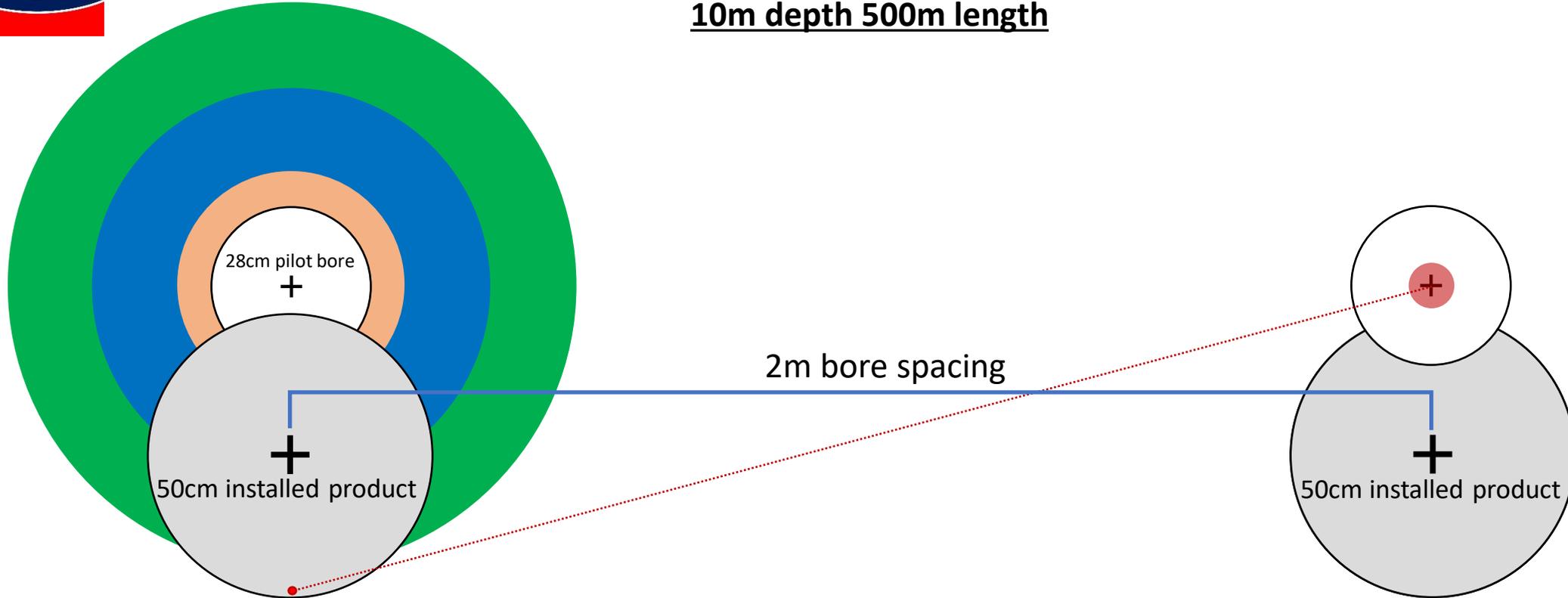
Surface Tracking error: +/- 20cm
Gyro Survey error: +/- 35cm
Walkover error: +/- 50cm
Installed product after reaming (in soft formations)
Tracking wire in the installed product

Parallel Tracking error: ~+/- 4cm

DCA Technical Guidelines 7.2.1.1.1

Scale: 1:10

Combination Tools: Gyro Survey + Tracking
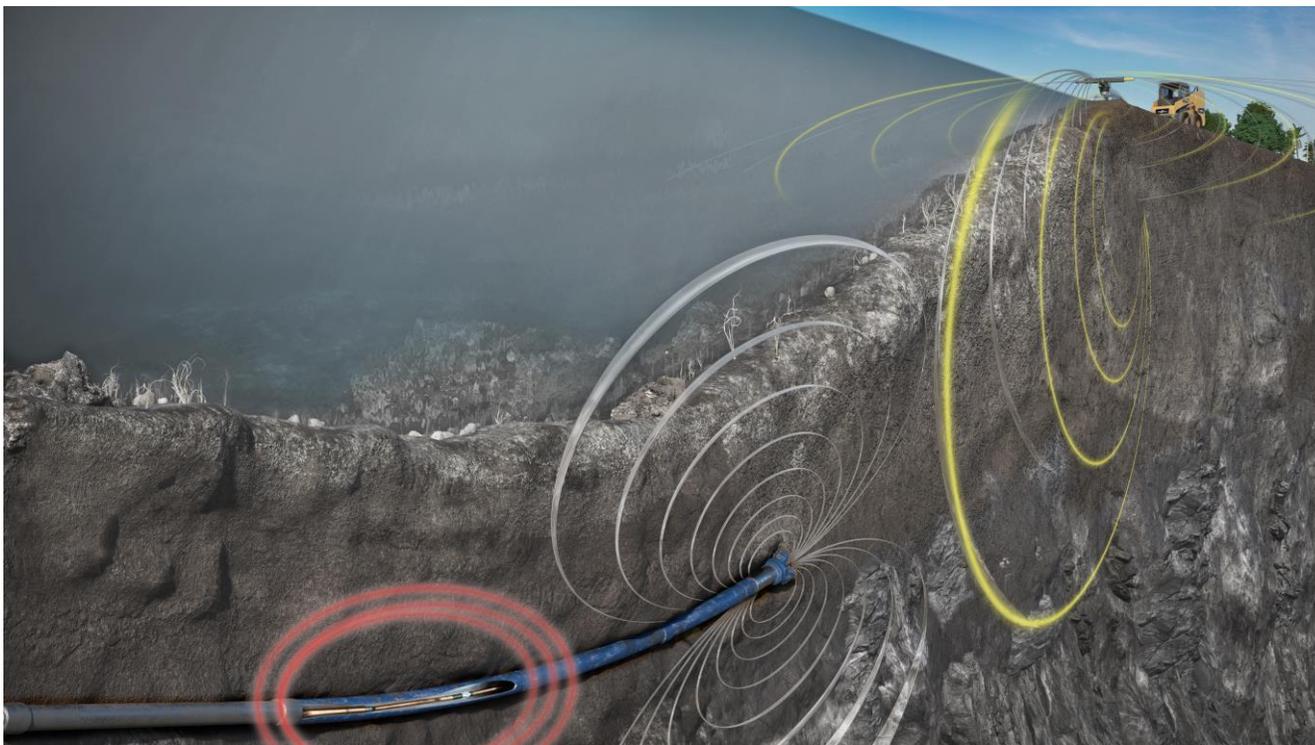
- Tracking in areas with surface access

- Gyro Surveys in areas without surface access

- Tracking corrects for accumulated Gyro Survey error

- Provides
  - Highest available accuracy
  - Options for demanding jobs
  - Competitive choice

Gyro

OPTICAL GYRO

DATA PROCESSING

ACCELEROMETERS
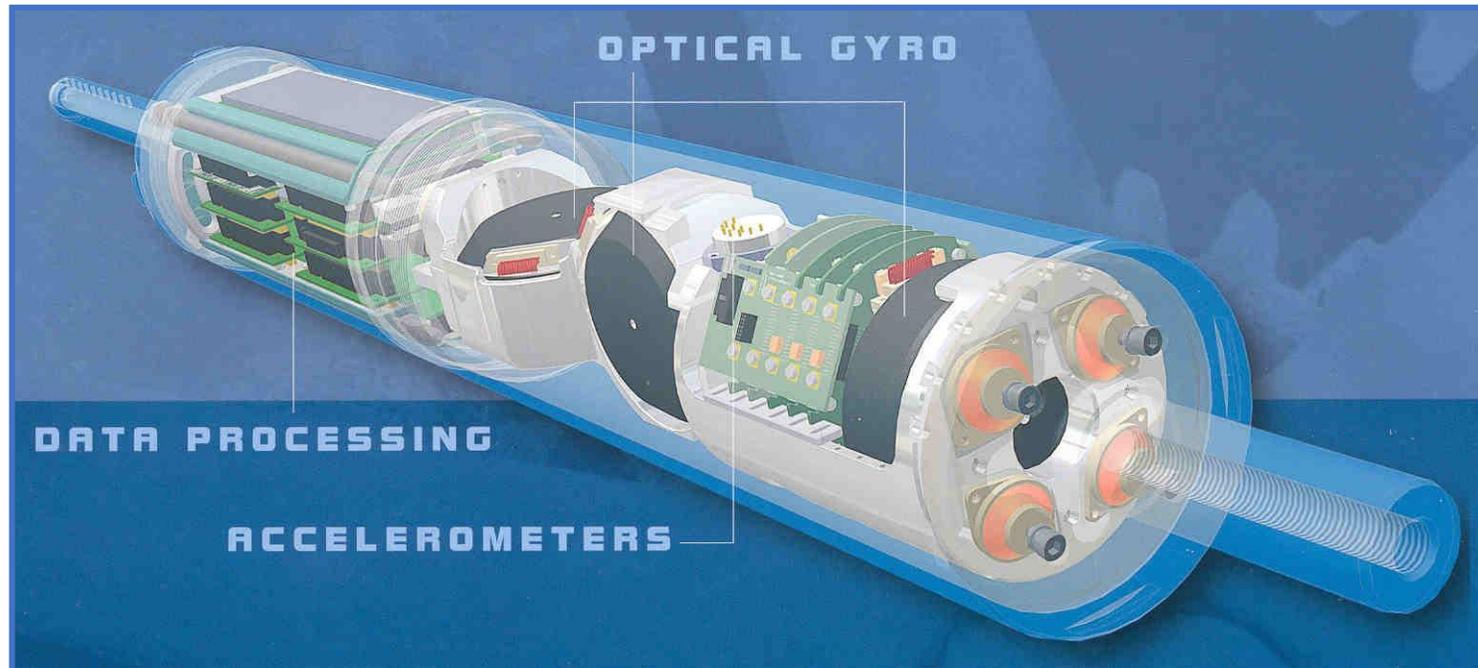
Gyro systems

Mechanical Gyro
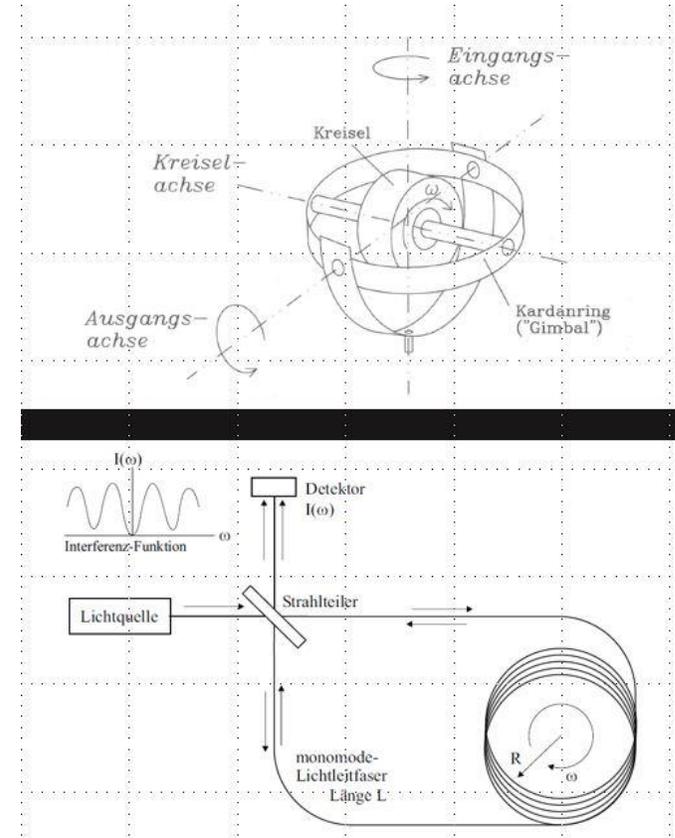
Optical Gyro

Sensor Position

Beacon housing

Jetting assembly

ABIA Bit Sub   Mud Motor   Steering Tool

Walkover: <1m

Gyro or Tracking Tools:

Jetting: 2.5 - 5m

Mud motor: 4.5 - 9m

At-Bit Inclination Assembly: <1m
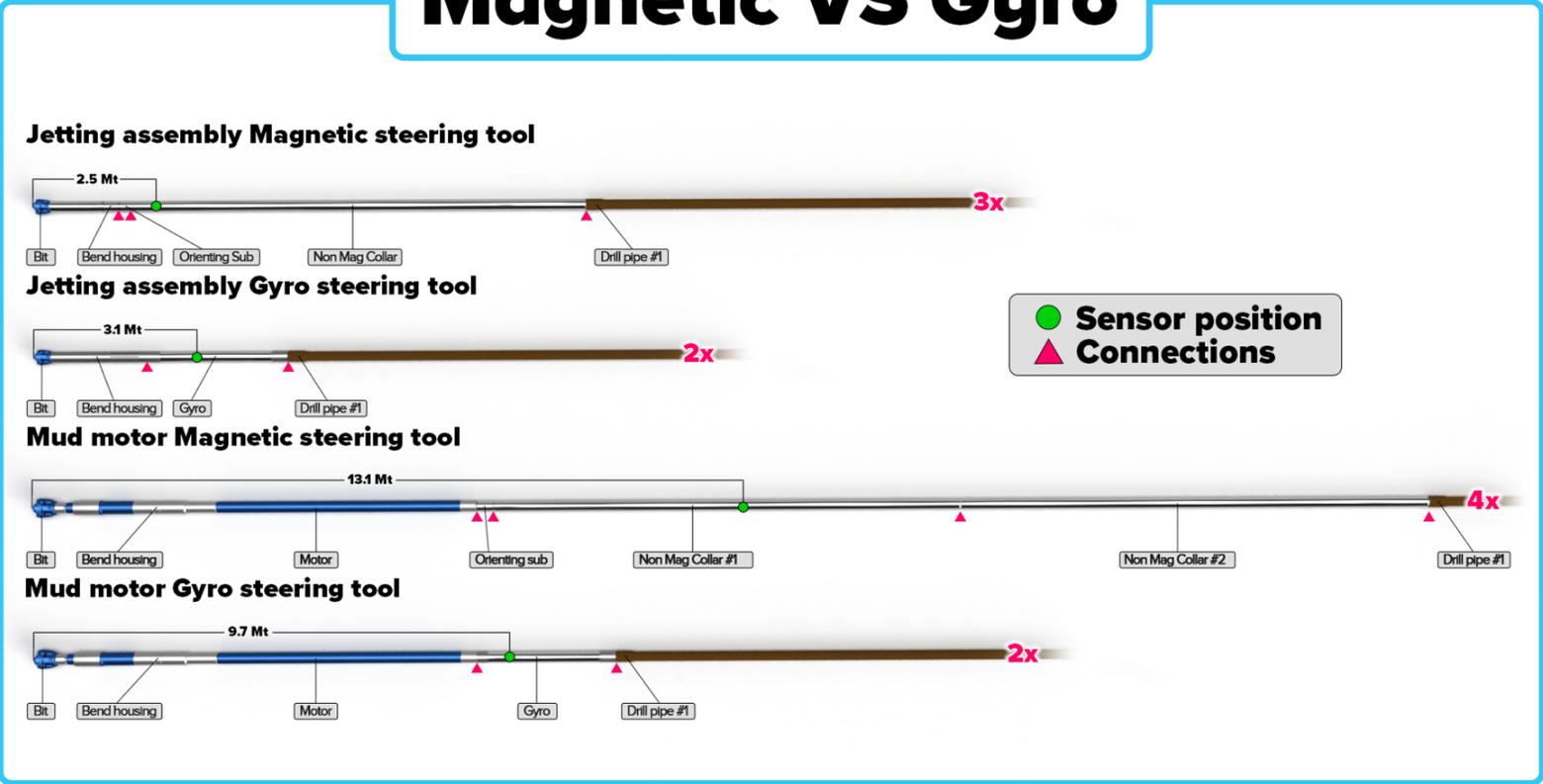
Walk over   <1m
Magnetic   13m
Gyro   10m

Stiff body is essential

• Complicated non-linear motions due to stiction, time-variant parameters etc.
• Interaction between rotational dynamics And lateral motion

Driving moment

Lateral force

Axial force

DRILL-STRING

Drillguide GST

Bent sub 2 degrees

DRILL-BIT

Random force

Bit moment

Stiff rigid body ?

Lateral drillstring motions
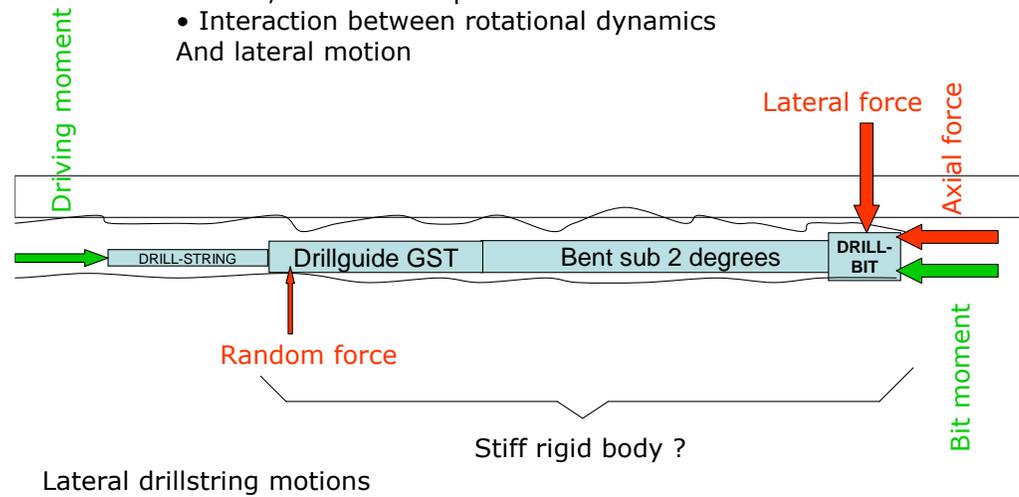
Accuracy

	Walkover	Magnetic	Gyroscopic
Inclination	+/- 0.10 Grad	+/- 0.10 Grad	+/- 0.01 Grad
(Pitch)	(RMS)	(RMS)	(3 Sigma)
Direction		+/- 0.4 Grad	+/- 0.04 Grad
Azimuth		(RMS)	(3 Sigma)
Depth	max 50m	No limits	No limits
	accuracy decreeses with depth.	accuracy decreeses with depth.	
Accuracy	5- % of depth	2% of distance to cable	70 cm at 1000m length.
Sensitivity for interference	YES	yes, active and passive	No

Two Types of Uncertainty

Cumulative Survey Error

- Found in all tools that measure inclination and azimuth
  - Gyroscopic surveys
  - Magnetic surveys

- x, y, z coordinates calculated based on previous x, y, z and current survey measurement

- Error propagates along the bore
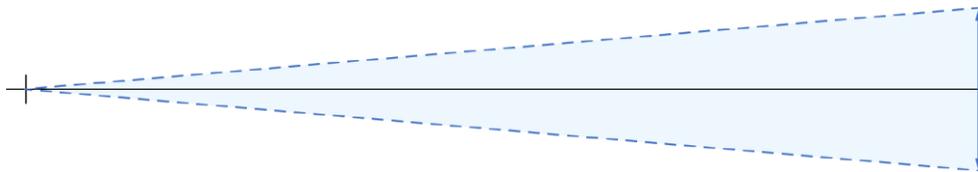
Direct Measurement Error

- Found in all systems that use direct measurements to an independent source
  - Walkover locator
  - Magnetic tracking
  - GPS tracking

- x, y, z coordinates measured directly

- Magnitude of error is proportional to distance from source

- Error does NOT propagate
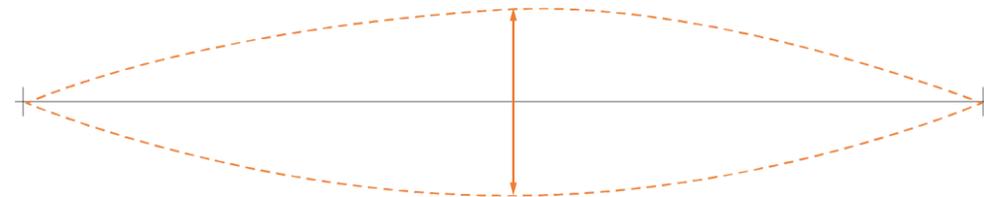
Two Types of Uncertainty
Influence of Distance to Source

Bore Depth: 10m, Bore Length: 1000m
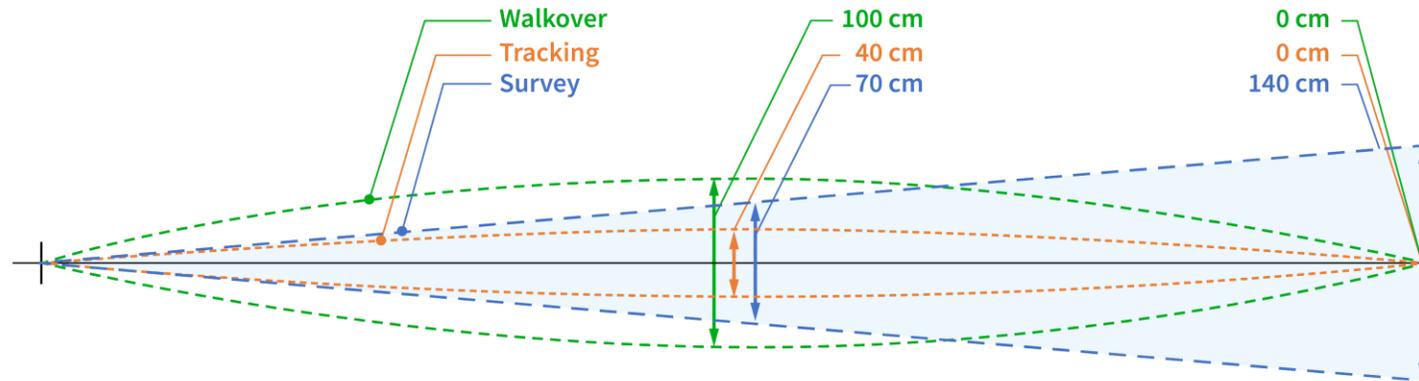
- Gyro Survey uncertainty accumulates with length (0.04°)
- Tracking uncertainty increases with distance from magnetic source (2%)
- Walkover uncertainty increases with distance from magnetic source (5%)

Accuracy of accuracy

Pitch measurement accuracy : 0,02 degrees (3 Sigma)

Azimuth measurement accuracy: 0,04 degrees (3 Sigma)

1000m long 40m Deep without interference
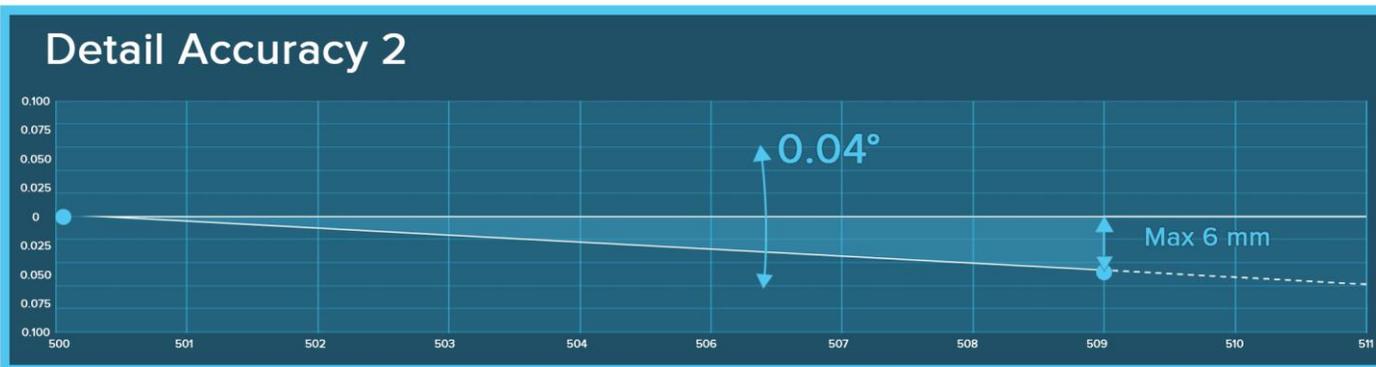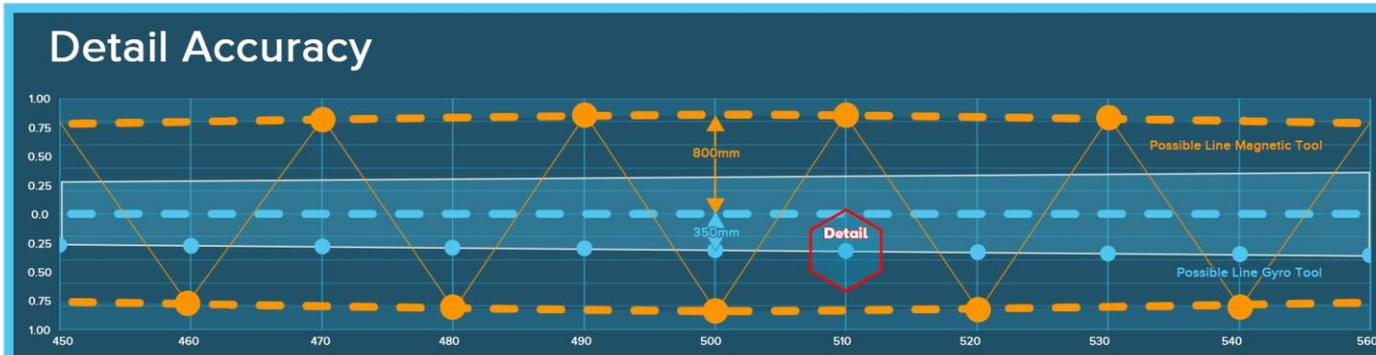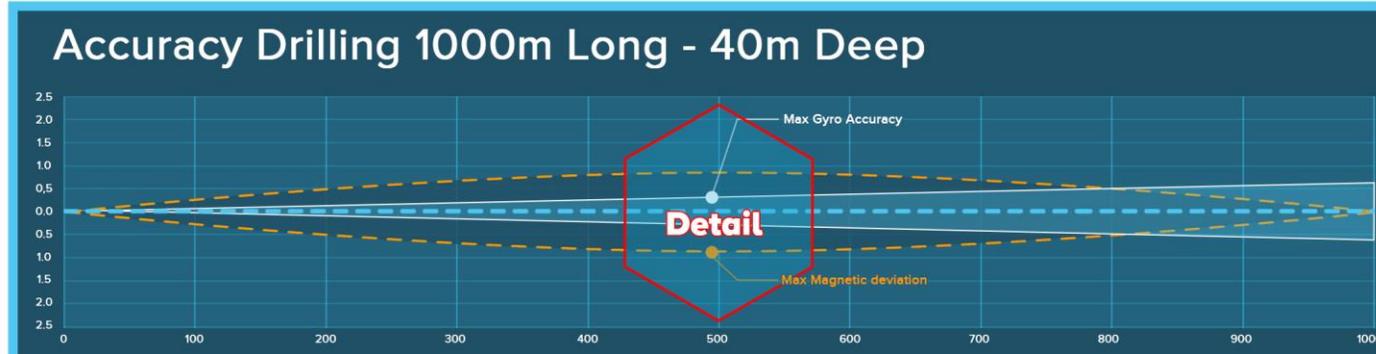
HDD Guidance Systems Comparison

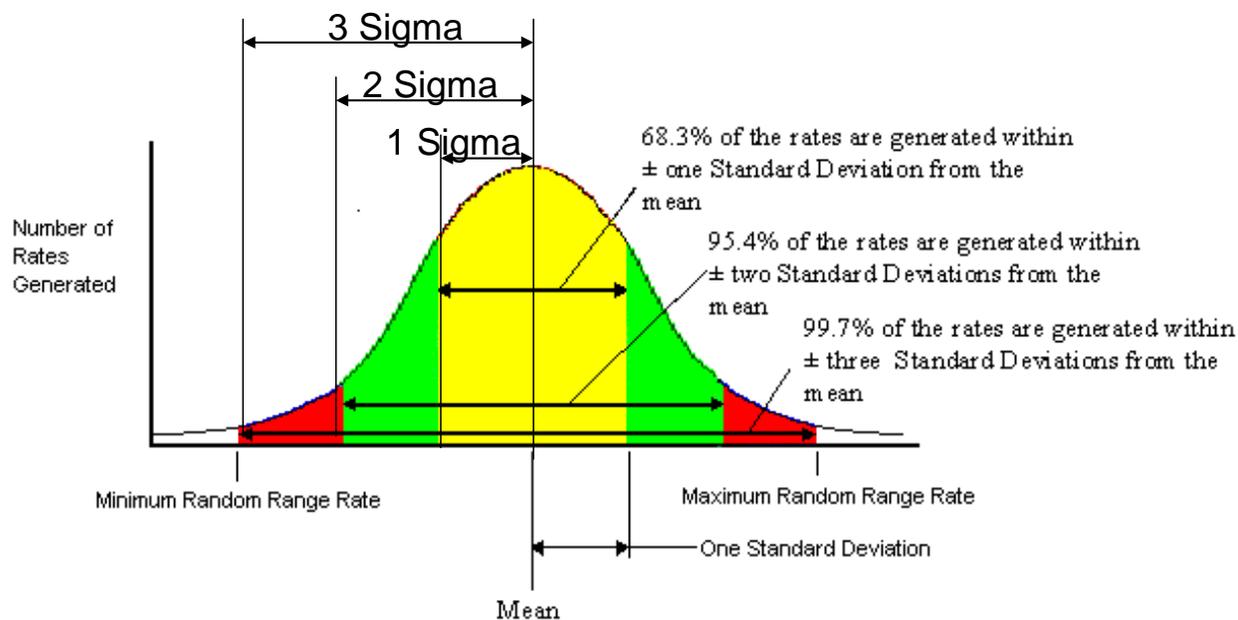| Guidance Method	Accuracy over Length			Accuracy over Depth				Susceptibility to interference	Ease of setup	Speed	Cost
	<250m	250-1000m	>1000m	<15m	15-50m	50-100m	>100m				
Walkover	🟢	🟢	🟢	🟢	🟡	🔴	🔴	🟡	🟢	🟢	🟢
Magnetic Tracking	🟢	🟢	🟢	🟢	🟢🟡	🟡	🟡	🟡	🟡	🟡	🟡
Gyro Survey	🟢	🟢	🟡	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟡
Magnetic Tracking + Gyro	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡🟡
Gyro + GPS tracking	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟡🟡

How is it controlled?

- Locating, Procedure, Accuracy
- Directional control

- What affects directional control?
- Driller and the DD - human-factor
- Limits of each Steering tool
- Soil
- Drill rod diameter
- Tools: Drill head - Reamer, etc

What influences the required spacing of the cables?

- Influence of drilling line design on steering- and position accuracy

  - Design radii:
    - Small, tied radii
      The smaller the radii, the more the ground is stressed during steering (activation of the passive earth pressure) Narrow radii generate additional thrust forces during pilot drilling, which can lead to steering problems with increasing drilling length.
    - Especially in the start section of HDD boreholes, narrow radii should be avoided
  - Distance of parallel holes
    - In the case of parallel holes, the distance must be chosen in such a way that subsequent holes are not affected.
    - The ground in the start and target area must not be "softened" by the previous borehole
    - When designing the distances, the mud-pressure should also be taken into account (D-Geo Pipeline). If the distances are too short, there may be a "hydraulic short circuit" between adjacent boreholes. This effects the drilling hole cleaning and thus also the steerability.

The more accurate / higher the requirements, the higher the effort or lower the drilling progress
=> more accurate = more expensive

What influences the required spacing of the cables?

Influence of the drilling program on the position accuracy

- it goes without saying that the most technically and economically suitable measurement technology is to be used

- choosing the right drilling tool is extremely important for pilot drilling accuracy. Factors such as geometry of the bottom hole assembly; the angle and length of the bend-sub, bendhouse setting, nozzle configuration must be adapted to the expected soil-situation and the planned drilling alignment.

- The experience or ability of the driller is also a decisive factor. A good driller distributes the change of direction over the entire length of the drill rod (avoids the so-called "dolphin drilling"). This ensures a "smoother" drilling alignment and increases steerability even with increasing length

- From a certain bore length, the thrust forces are so high that good steering is no longer possible. This effect can be countered by using stiffer drill rods (e.g. 7 5/8" drill rods) or the use of mud-motor also in the jet-able ground conditions (advisable from of L >2000m).

What influences the required spacing of the cables?

- with each reaming step, the position of the borehole changes slightly from the alignment of the pilot borehole

- => rather a few large reaming steps than many small ones (provided you have the appropriate high-torque drill rigs and a drilling fluid with sufficient carrying capacity)

- Large pilot drilling diameters and / or pipe installation while reaming can prevent or reduce any position deviations caused by enlarging the borehole

- by choosing the right reaming tools and using suitable centering tools, the position accuracy can be significantly improved. (Reduction of the keyhole effect, if necessary "lift" the design of the pilot drilling alignment)

Can the required position accuracy decrease by considering conservative assumptions?

- Rating against nominal temperature, which is determined very conservatively - manufacturer's guarantee.
- Thermal stress for steady-state conditions that are unlikely to occur during the lifetime of the cables
- Soil is an inhomogeneous material
- Thermal resistance is assumed for dry soil
- Air-filled cable protection tube: Transition cable - PE

- Ensuring the functionality of the cable -
100% network stability

Measurement of the product line supplies

- As-build-information linear x, y, z
- bend radius – integrity assessment
- lessons learned
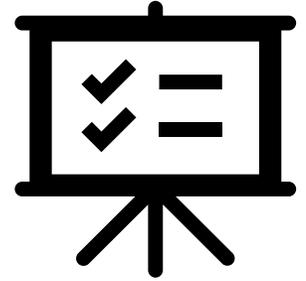
Post-pullback mapping is always a good idea

Why gyro after pullback?

- You are creating an as-built of the actual utility pipe.

- Any profile change introduced during reaming is captured

- True and accurate bend radius can be calculated

- Incremental time required is minimal

- It's the last time the pipe is easily accessible

But gyro systems can be used for more than as-builts …..

Locating lost drill head in tunneling project

Gyro mapped path
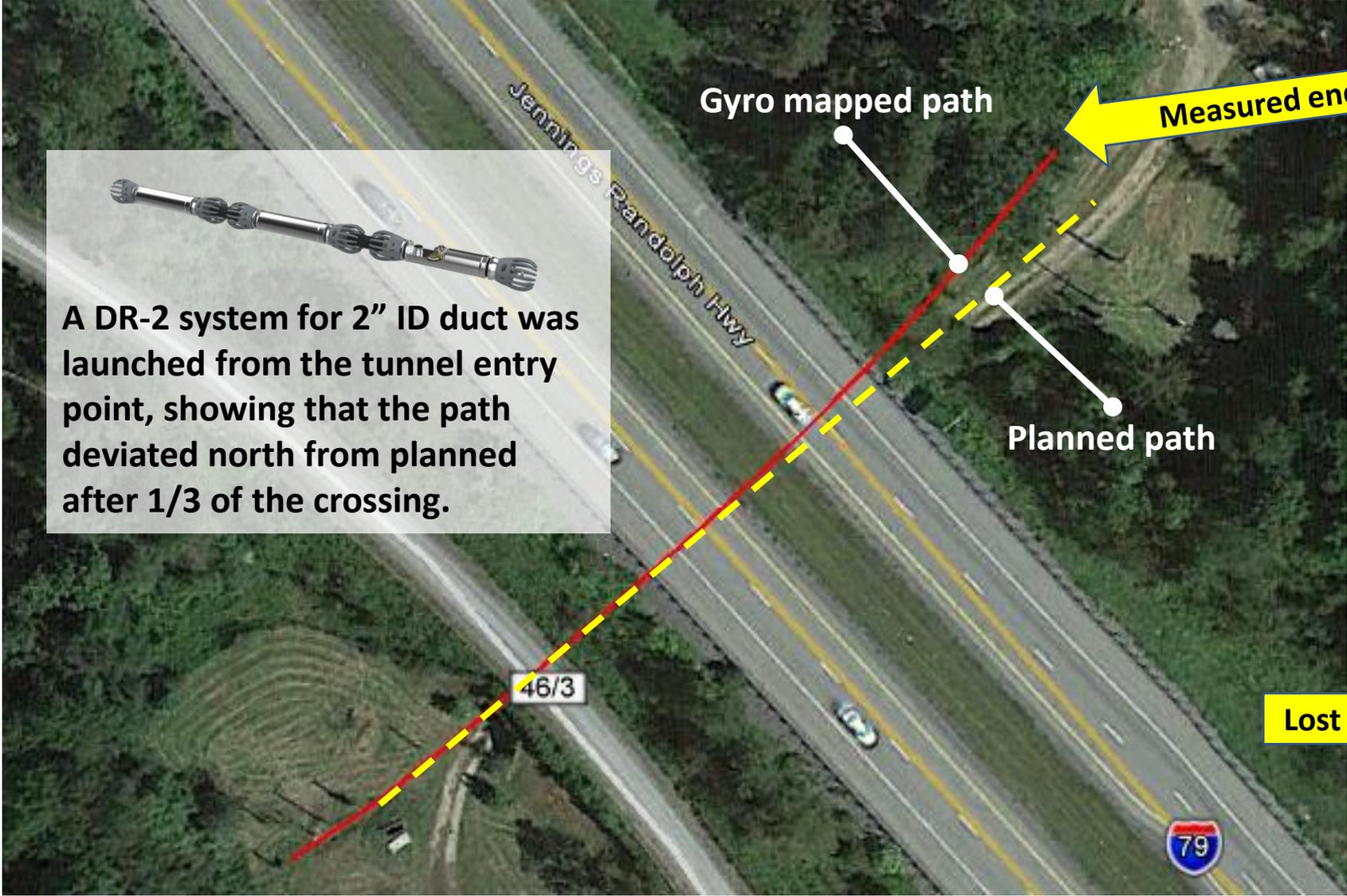
Planned path

A DR-2 system for 2" ID duct was launched from the tunnel entry point, showing that the path deviated north from planned after 1/3 of the crossing.

Measured end point was staked

Lost drill head was found

Pipe bundle torque assessment

A bundle of 6 power grid pipes ready for pull in could not be lined up with a new 975m long HDD, so there were three 90-degree corners, causing the bundle to torque.

To avoid excessive stress on future power cables, the owner did not want the bundle to torque inside the HDD, but did not know how to verify that.
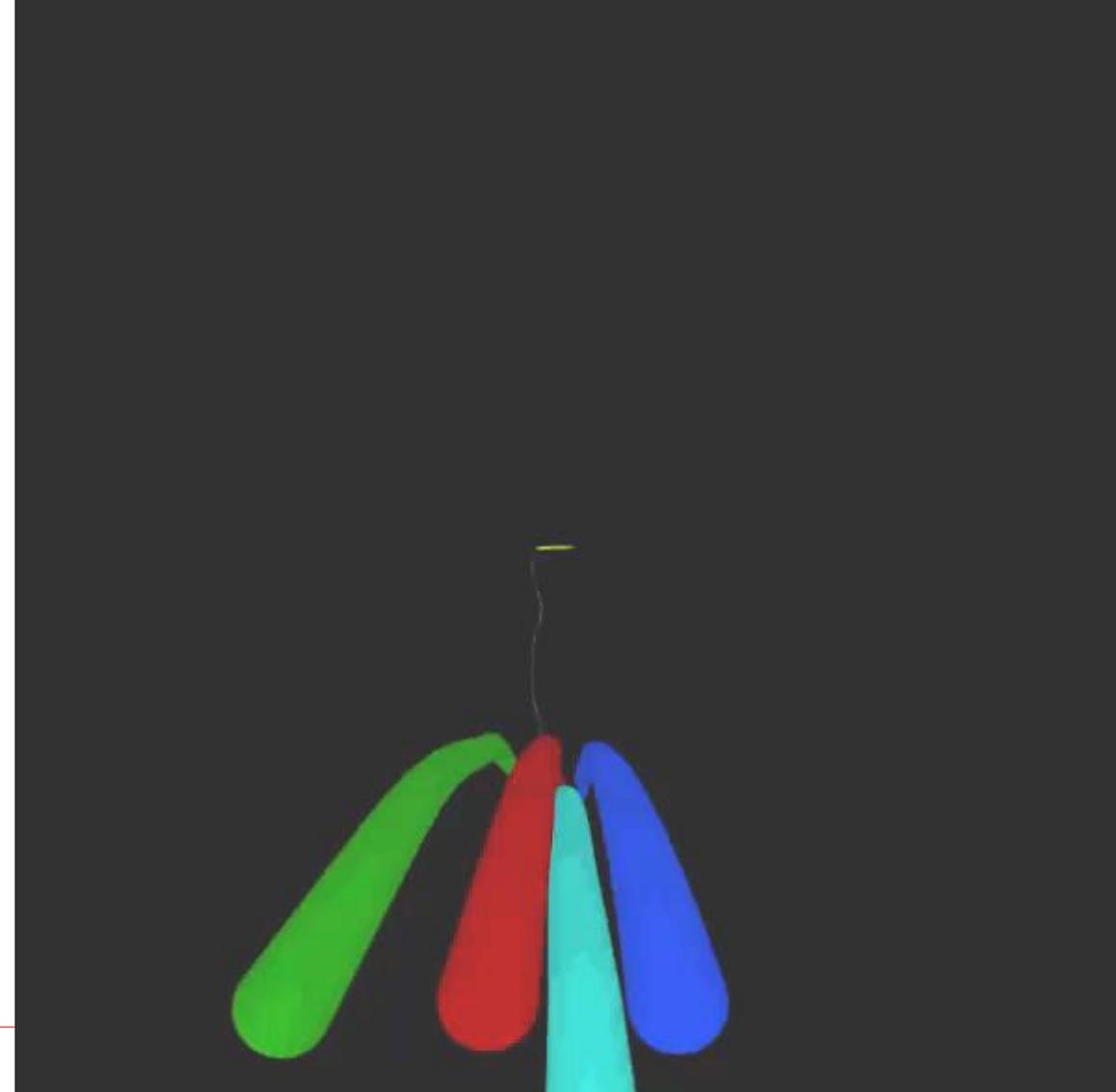
HDD

6 x PE pipes awaiting pull in

Pipe bundle torque assessment

- After pullback, four pipes were mapped using standard DR-4 mapping system.

- The resulting profiles were loaded into GIS platform.

- 'Fly-over' projection was made to assess the level of torque of the bundle along the 975m HDD (click ▶ to start).

- Conclusion, no excessive toque

Drill head (string) and soil stiffness

Additional slides Henk Kruse
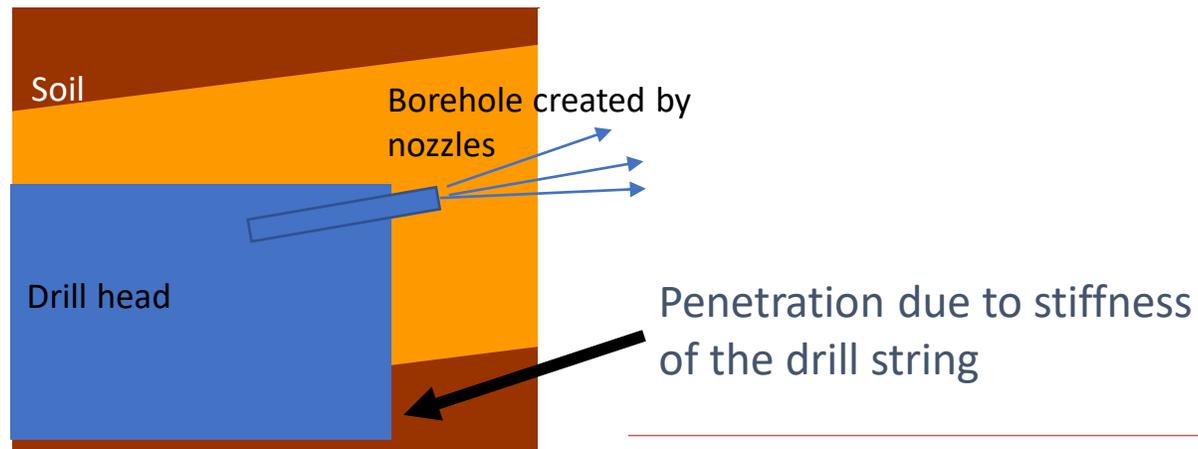
Soil pipeline interaction in curved section
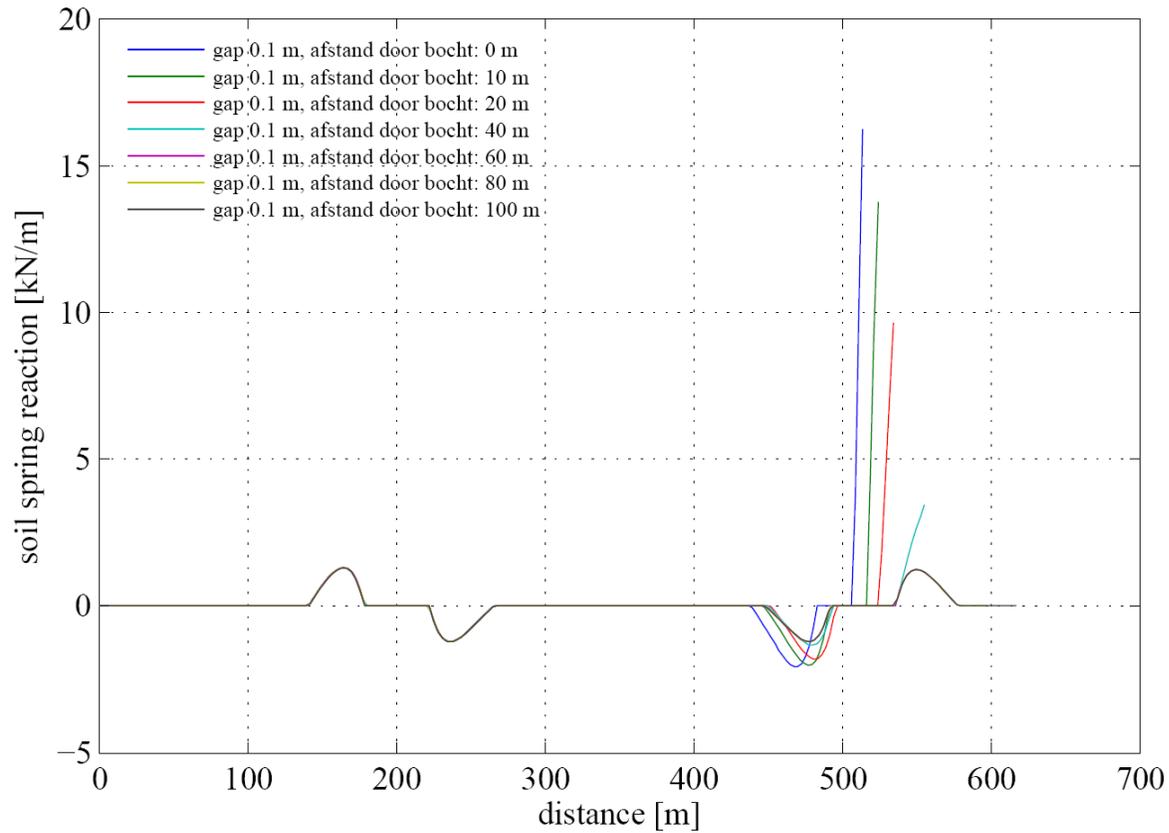
$$M = \frac{EI}{R}$$

M   = Bending moment [kNm]
E   = Modulus of elasticity of drill pipe material [kN/m^2]
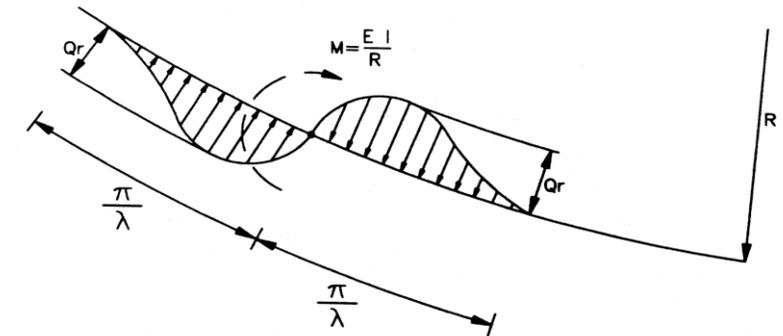I   = Moment of inertia [m^4]
R   = Bending radius [m]

Soil

Borehole created by nozzles

Drill head

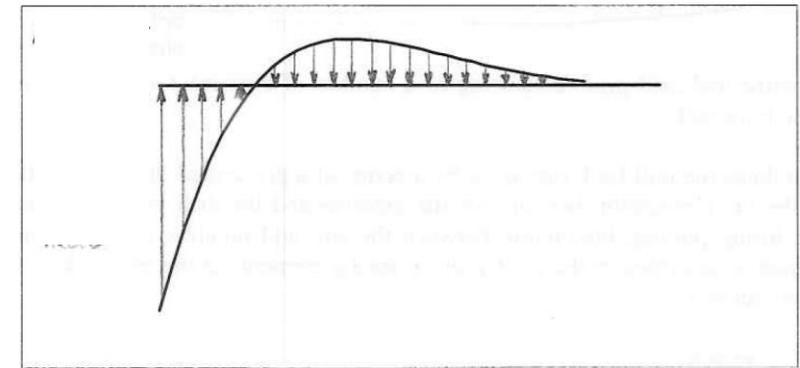Penetration due to stiffness of the drill string

Soil reaction (gap = Borehole)

Drill string entirely in the curved section

Drill Head in the curved section

Borehole wall penetration (soil penetration that contributes to the final drilling line position)