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Steering the HDD

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1. ABSTRACT

- **Trenchless Technology is continuously improving and expanding beyond it's limitations.**
- **HDD drillings are getting longer and longer and we execute intersect drillings in very complex soil conditions.**
- **We drill more and more in very congested area's with several other services within in the vicinity of the planned route.**
- **Drilling routes are quite complex with all sort of requirements, like drilling in the best soil layers, allow for enough cover to avoid mud blowouts, allow for sufficient tolerance with existing infrastructure, etc. etc..**
- **Several curves will be applied in the route to steer the optimum drill line.**
- **All this design data will be used to calculate the theoretical pulling forces with our usual calculation programs and then we add a safety factor of 40% for unforeseen circumstances.**
- **These calculations are still the same as we used several years ago with the large safety factor for several risks. And because the uncertainty of the soil parameters, we certainly need a substantial safety factor.**

But some of this safety factor is quite often used for tolerances in the drilling, when a deviation must be compensated, or interference is disturbing the measuring.
We can reduce this part of the safety factor, when we follow the drill line more accurate and use a system where interference is not influencing the measuring.
Accurate measuring can reduce the pulling forces of the drillings and will give more certainty of the final position of the drilled profile.

For steel pipes, it also will give more certainty about the pipe stress caused by the radius of the drilling and herewith the remaining pipe stress for pressurising, if required.

Also the risk for coating damage is reduced when the drill line is more smooth and no additional curves are drilled to compensate deviations in the profile.

2. INTRODUCTION

I believe we know much more about HDD than 15 years ago, and hope we all are interested to improve the knowledge to stretch the limits and reduce the risks.

Recent years we improved our knowledge about steering and mud substantially and we use much better equipment than 15 year ago, but we still use the same calculation software or safety factors.

We noticed, HDD drillings executed with a gyro steering tool are giving a smoother drill line and lower pulling forces.

It is nowadays possible to measure the pipe position accurate enough to calculate the bending radius after installation and see the differences with the different steering tools.

After several checks with the different steering tools, we noticed the drillings executed with the gyro steering tools are much smoother, and for larger diameter pipelines, this will give substantial lower pulling forces. Unfortunately the information is well known, but the calculation programmes are still the same.

I hope together with all of you, we can collect sufficient data to improve our calculation programs and to reduce the risks for pipes and drillings.

I propose to deviate the safety factor, based on the different systems, to promote the use of accurate steering, and to stimulate the knowledge of pipe stress caused by drillings.

With magnetic tools you check and measure with an accuracy of 1-2% of the depth if there is no interference, which will give a possible deviation of 40-80cm at 40m depth (16-32 inch at 130 feet). Your next measurement can be 40-80cm (16-31 inch) the other way, which will give a deviation of 80-160 cm(32-64 inch) within two joints of normally 9m(30 feet). If I only take 80cm (32 inch) within two joint of 9m (30 feet), you will get a additional bend of 2,5 degrees, which will cause a substantial higher bending radius as designed.

With the tolerance of a Gyro system the maximum deviation within 18m (60 Feet) is 0.04 degree = 13mm (0,5 inch) independent of the depth.

With magnetic tools you also you have the risk for disturbances, or area's where it is not possible to layout a proper surface cable, or where a parallel pipeline with Cathodic protection is disturbing the accuracy, all giving more risks for a deviation of the planned route and designed radius.

Especially for larger diameter pipelines you will see substantial lower pulling forces when you drill with a Gyro steering tool.

3.1. BODY-HYPOTHESES

There are substantial differences in steering tools, and we still use the same parameters for all the different tools, although there are differences.

In the calculation we use for pipe stress: $\sigma = M/W$, and $M = Fko * E * I / R$ (note1)

Where Fko is 1,4 which means a safety factor of 40%

And for pull forces we also use this safety factor.

This is for uncertainties, which was introduced for several different risks as we had over 15 years ago.

Some of these uncertainties are still difficult to eliminate, like soil risk and unforeseen obstacles in the underground but for the deviations in mud weight or steering accuracy, we suppose there is much better technology and much more knowledge available, or didn't we learn anything the last 15 years?
I think it is not necessary if we still use this safety factor for mud weight uncertainties and steering tolerances.

3.2. BODY-EXPERIENCE/RESEARCH

Several studies are made and papers are given regarding large diameter HDD drillings.

Gasunie Holland executed a few years ago some large projects with over 30 no 48 inch HDD drillings, and compared the pulling forces between calculated and actual. (reference 1)

See figure nr 1 & 2

If you evaluate these results you see the pull forces are substantial lower as calculated.

These drillings where executed with the Gyro, and the Bentonite parameters where measured much better as before.

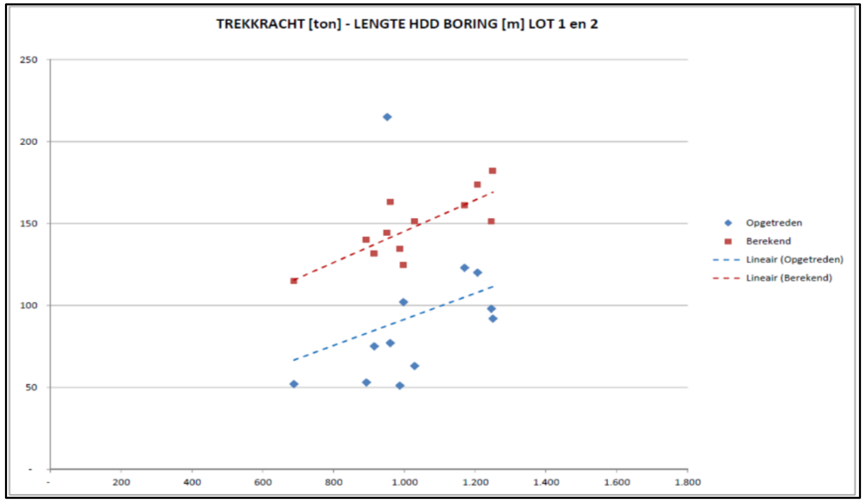


Figure 1: In Blue actual, and in Red calculated pull forces.

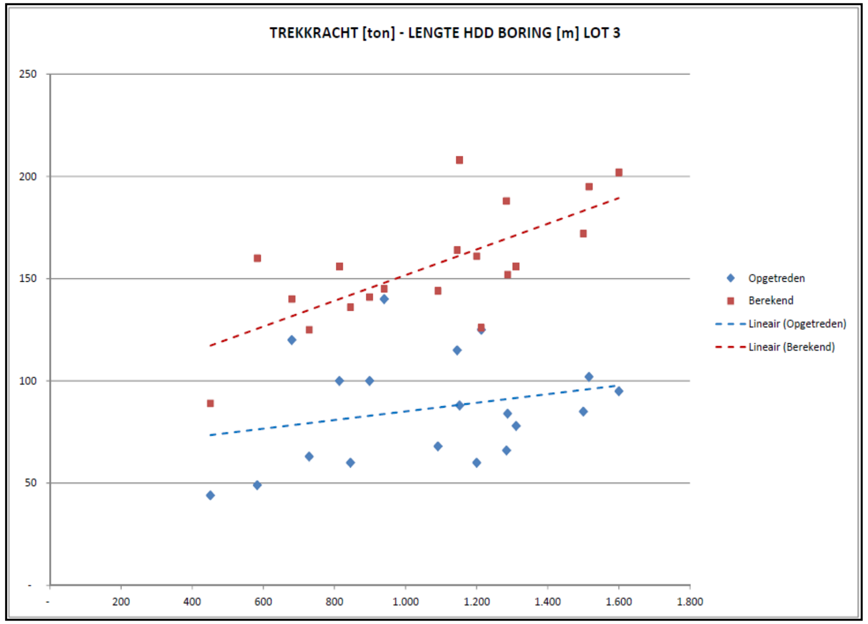
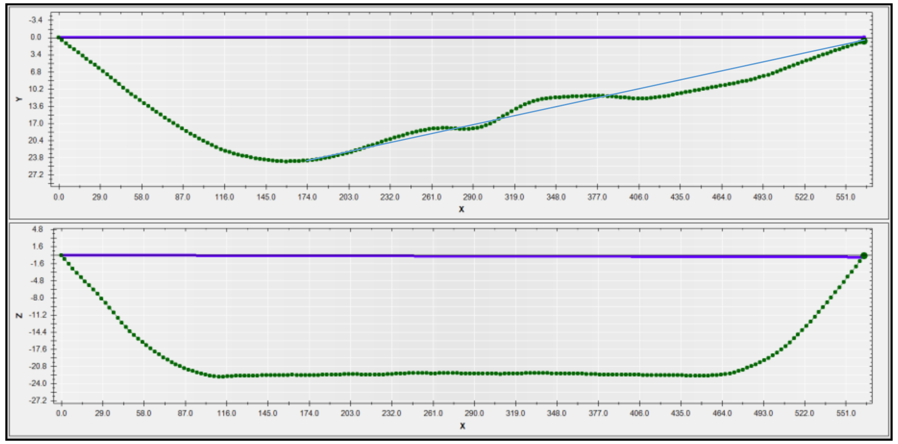


Figure 2: (in Blue the actual, and in Red the calculated pull forces)

Also several checks were executed to compare as built data from HDD drillings executed with magnetic tools and drillings executed with gyro tools.
See figure nr 3 & 4 & 5.



Plan View, and Longitudinal section

Figure 3:

You see a plan view and a longitudinal profile of a pipeline drilled with a magnetic tool, where entry and exit were quite accurate and originally everybody was satisfied about the line.
But after a check they noticed the line had a deviation of about 5m.

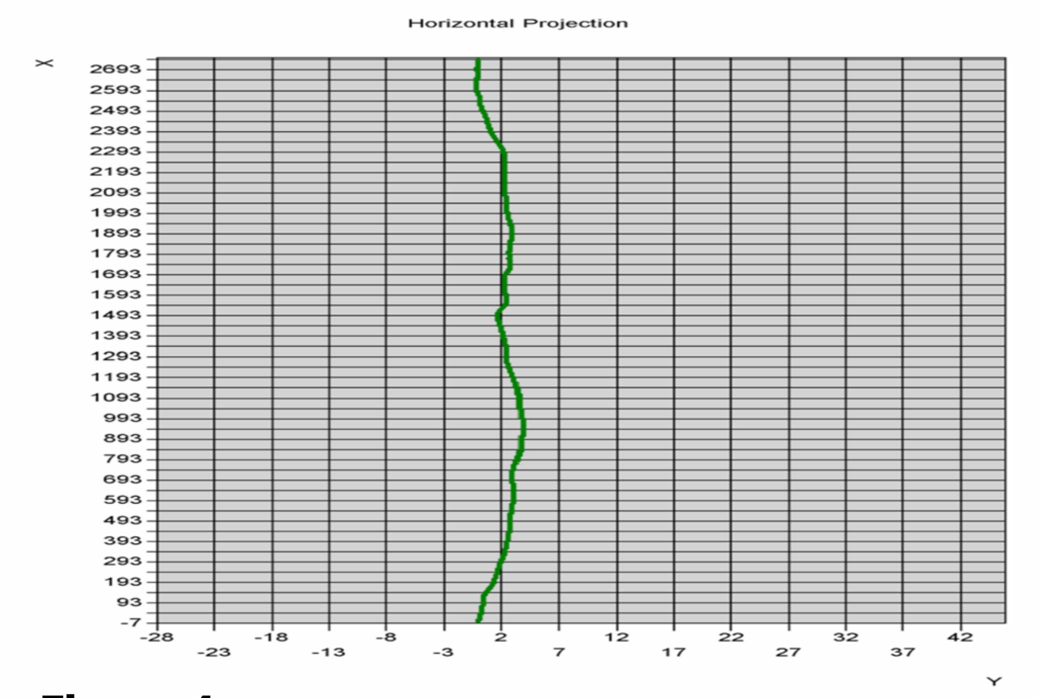


Figure 4:

You see only a plan view of a drilled pipe which should be straight and were also entry and exit were quite accurate.

According to the steering company this was a perfect drill line with an accuracy of a few cm, based on the punch out within a few cm.

After a track check measurement trough the installed pipes, the Client noticed several deviations all over the route till over 5m.

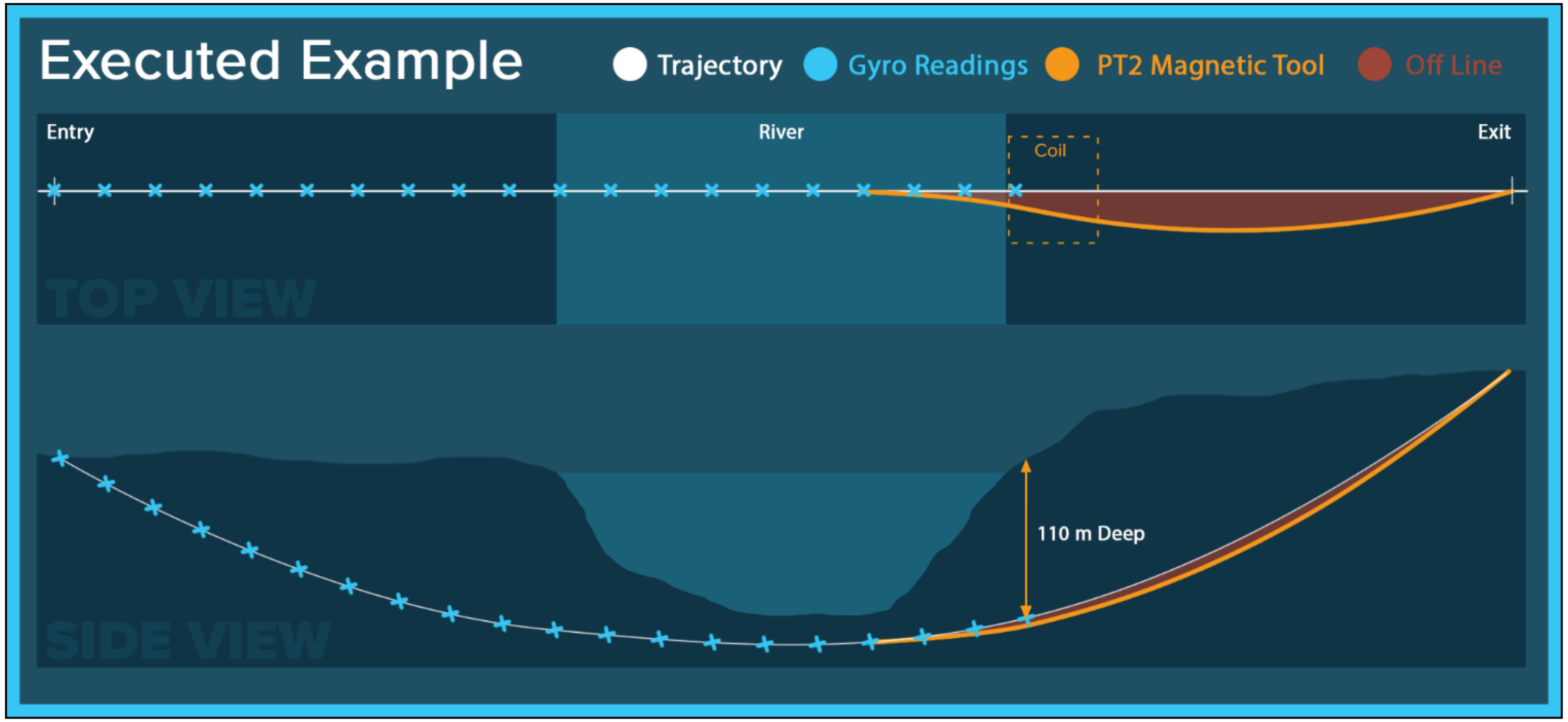


Figure 5:

Recently a 1200m long and 100m deep HDD which was installed partly with a Gyro steering tool and partly with a magnetic tool. Finally the whole line was checked with several Gyro systems. The HDD contractor decided to use the Gyro for only the river crossing where laying out a coil cable was impossible. The remaining section after the river crossing was drilled with a magnetic tool to save some money. The steering company who executed the remaining part was convinced about the position of the line but the end Client required a verification to make sure the pipe was in position and a possible parallel drilling could be installed safely.

The initial check run showed a deviation compared to the first section within a few inches and gave a deviation of 10m compared to the as built of the second part, which was drilled with a magnetic tool.
After many discussions with all involved parties, like HDD contractor, end Client, engineering firm, Steering company, manufacturer of the tools, etc etc., the end Client decided to execute a second check with a third party. This company used a different Gyro tool completely independent of the first Gyro check. This second check gave exactly the same position for the pipe as the first Gyro Check. After this verification, all parties were confident about the accuracy of the Gyro, and became aware of the risks of steering with a magnetic tool.
The HDD contractor was lucky he had to pull only a 8 inch line, where additional forces due to the tight radii where not really an issue.

3.3. RESEARCH

HDD drillings executed with a gyro steering tool are giving a smoother drill line, and lower pulling forces.
Several HDD drillings were checked with a Track Check system to verify the exact position of the pipeline.
It is possible to measure accurate enough to calculate the bending radius of a pipeline after installation, and even, to see the differences with the steering tools.

After several checks we know, drillings executed with a gyro are much smoother and for larger diameter pipelines this will give substantial lower pulling forces. This information is well known (in Holland) and more and more pipeline owners require Gyro steering for their HDD drillings but the calculation programmes are still the same.

I propose to deviate the safety factor, based on the different steering systems to promote the use of accurate steering and to stimulate the knowledge of pipe stress caused by drillings.

Track Check Tool.

3.4. THEORETICAL

As mentioned: With magnetic tools you measure with an accuracy of 1-2% of the depth if there is no interference, which could give an possible deviation of 80cm at two joints which is 2,5 degree, which will give a substantial shorter bending radius as designed.

With the tolerance of a Gyro system the maximum deviation within 18m (60 feet) is 0.04 degree = 13mm (0,5 inch), independent of the depth.

Drilling with a Gyro could also have possible deviations of the line, but only at long distances from the starting point, and it will be still a smooth line.

The mostly used Gyro will have a tolerance of 0.04 degree, which will give a maximum deviation of 70cm (28 inch) at 1000m (3300 feet).

At figure 6 you can see the maximum deviations of the drill line with the Gyro and with a Magnetic tool, for drillings of 1000m (3300 feet).

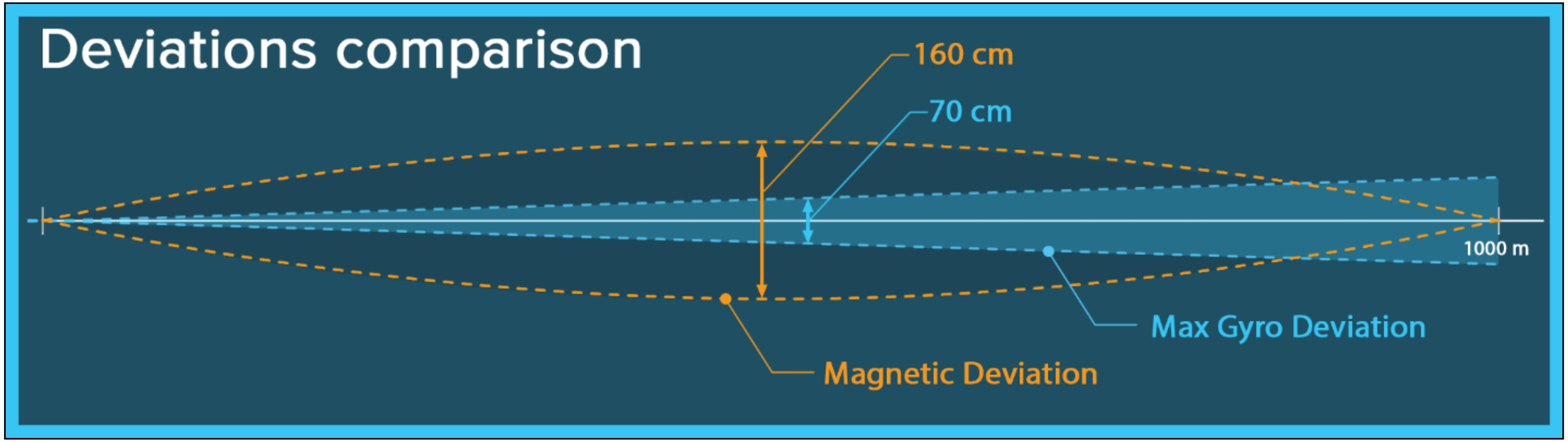


Figure 6:

If you don't encounter magnetic disturbances, and you can layout a proper coil at the surface, you must be able to stay between the orange stripes line if the drilling is less than 40m deep.
With the Gyro you will stay within the blue stripes line, independent of the depth.

At figure 7 you can see the deviations over a 50m (160 feet) section of the line where the gyro will always give a smooth line, and the accuracy of the magnetic tool is depending on depth, interference, coil cable, ect.

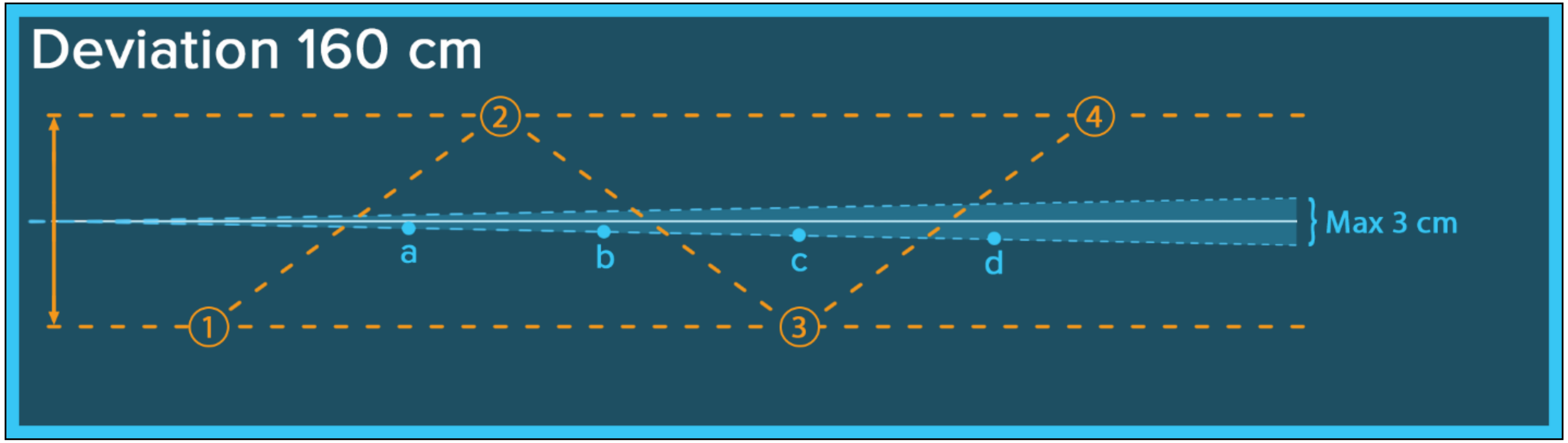


Figure 7:

This (in)accuracy could give quite some deviations causing additional friction.
A substantial part of the safety factor in the calculations could be required already for the additional bends.

With magnetic tools you could have a drill line in orange (from 1 to 2 to 3 and 4)
With the Gyro you could have a line in blue (from a to b to c to d)

With magnetic tools you also you have risk for disturbances, or area's where it is not possible to layout a proper surface cable, or where a parallel pipeline with Cathodic protection is disturbing the accuracy, all giving more risks in a deviation of the planned route and designed radius.

Especially for larger diameter pipelines you will see substantial lower pulling forces when you drill with a Gyro steering tool.

3.5. CALCULATION PROGRAM

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If you drill with a radius 70% of the design radius, you will have in the bends a pro rata higher pipe stress caused by the bending radius.

- **σ=M/W, where M=E*I/R.**
- **If R=70%, the pipe stress σ due to the curve will be 1/70% =** 140%

This will give more friction, caused by additional bending. In combination with the friction caused by the surrounding bentonite it will give a substantial higher pull force.

$$Q_r = k_v . y = \frac{0.322.\lambda^2.EI}{D_o.R}$$

with:

$$\lambda = \sqrt[4]{\frac{k_v.D_o}{4.EI}}$$

where:

Qr =	maximum soil reaction near the end of the bend	[N/mm2]
kv =	vertical modulus of subgrade reaction	[N/mm3]
y =	maximum displacement	[mm]
EI =	bending stiffness of the pipe	[Nmm2]
R =	radius of the bend	[mm]

Herewith you see the soil reaction Qr is linear with the radius, and herewith the Pull forces.
If R = 70% of the design Radius, the pull force will be 1/0,7 = 140% of the theoretical forces.

At figure 8, you see a summary of a usual pull force calculation with 70% of the design radius, and at figure 9, the pull force summary with the design radius (reference 2).
You see a total of 115 Ton (230 lb) and 95 (190 lb)Ton for the theoretical pull Forces. And this is only if the additional bending is only at the bending sections, while we know, there is also additional bending in the straight sections, when steering with magnetic tools.
An additional pulling force of 40% is not exceptional if you drill with a magnetic tool in difficult circumstances, and pulling larger diameter steel pipe.

4.5 Aggregate of tensile forces in phase II

Tensile force T_{tot} in various stages [N]	T_1 [N]	T_2 / T_{3a} [N]	$T_{3b,neer}$ [N]	$T_{3c,neer}$ [N]	$T_{3b,op}$ [N]	$T_{3c,op}$ [N]	T_{tot} [N]
Pulling 1st part	770.152	15.630	-	-	-	-	**785.783**
Pulling 2nd part	586.028	114.657	323.109	59.929	-	-	**1.083.722**
Pulling 3rd part	213.187	315.179	323.109	59.929	-	-	**911.403**
Pulling 4th part	29.062	414.206	323.109	59.929	271.701	60.765	**1.158.771**
Entire pulling	0	429.836	323.109	59.929	271.701	60.765	**1.145.339**

$T_{tot} = T_1 + T_2 + T_{3a} + T_{3b\ neer\ max} + T_{3c\ neer} + T_{3b\ op\ max} + T_{3c\ op}$

Figure 8: (according Sigma)

4.5 Aggregate of tensile forces in phase II

Tensile force T_{tot} in various stages [N]	T_1 [N]	T_2 / T_{3a} [N]	$T_{3b,neer}$ [N]	$T_{3c,neer}$ [N]	$T_{3b,op}$ [N]	$T_{3c,op}$ [N]	T_{tot} [N]
Pulling 1st part	770.152	15.630	-	-	-	-	**785.783**
Pulling 2nd part	586.028	114.657	226.176	54.255	-	-	**981.115**
Pulling 3rd part	213.187	315.179	226.176	54.255	-	-	**808.797**
Pulling 4th part	29.062	414.206	226.176	54.255	190.191	50.320	**964.209**
Entire pulling	0	429.836	226.176	54.255	190.191	50.320	**950.777**

Figure 9: (according Sigma)

3.6. RESULT

- **We know for sure there are differences between the different steering tools, and they will lead to different conditions for the installed pipelines.**

- **We know there is sufficient information available to check the differences in the various steering techniques.**

- **We know it is possible to measure accurate enough to check the position of drilled pipelines.**

- **With more information we can make a better design, update our calculation programs and push the HDD to a higher level.**

4. CONCLUSION

- **LET'S Use our knowledge**
- **LET'S reduce the uncertainty factors in our technology.**
- **LET'S Improve the HDD industry**

5. REFERENCES

1: Eric Brink, 14 October 2014, NSTT Presentation.

2: Kees Schrijvers, Sigma HDD calculations according NEN 3650/51

Note 1: Standard European calculation according the NEN/DIN.

Any Questions ?