Code of Practice

Upstream Polyethylene Gathering Networks – CSG Industry

Companion Paper CP-08-004

Hydraulic and Pneumatic Testing Calculations

Rev 0

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Contents

Acknowledgements

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Preface

Companion Papers have been developed by the Working Group responsible for the *APGA Code of Practice for Upstream PE Gathering Networks – CSG Industry* (the Code) as a means to document technical information, procedures and guidelines for good industry practice in the coal seam gas (CSG) industry.

Since 2008, the development of the LNG export industry based in Gladstone, Queensland, with its related requirement for a large upstream CSG supply network of pipelines and related facilities presented the impetus for significant improvements in design and best practice approach.

The principal motivation for the initial development of the APGA Code of Practice was safety and standardisation in design and procedures, and to provide guidance to ensure that as low as reasonably practicable (ALARP) risk-based requirements were available to the whole CSG industry. Accordingly, the Code is focused solely on this industry and the gathering networks using locally- manufactured PE100 pipeline. The Code is a statutory document within Queensland.

The incorporation of Companion Papers in the Code is intended to provide information and best practice guidelines to the Industry, allowing the Code to be limited to mandating essential safety, design, construction and operation philosophies and practices.

These documents form part of the suite of documents together with the Code and are intended to:

a) be used in the design, construction and operation of upstream PE gathering networks
b) provide an authoritative source of important principles and practical guidelines for use by responsible and competent persons or organisations.

These documents should be read in conjunction with the requirements of the Code to ensure sound principles and practices are followed. These documents do not supersede or take precedence over any of the requirements of the Code.

A key role of the Companion Papers is to provide the flexibility to incorporate endorsed industry practices and emerging technologies expeditiously, as and when necessary.

A related benefit is that the Companion Papers can be referenced by the wider resources industry which uses similar PE gathering networks for gas or water handling, including coal bed methane (CBM) in underground coal mines, mine de-watering, the emerging biogas industries (agricultural, landfill, etc.), or any development with similar characteristics (e.g. shale gas).

1 Scope

The purpose of this Companion Paper is to provide guidance on the calculation of theoretical potential rock throw distances resulting from pressure test failures, for both pneumatic pressure testing and hydrostatic testing of PE100 pipelines within the Code of Practice, Version 6. It provides the possibility for a risk based approach to the required strength test using either compressed air or water. A successful strength test using compressed air negates the need to drain water from the pipeline and could also be preferable on steep gradients.

2 General

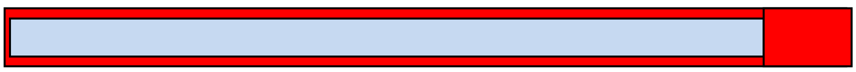
Exclusion zones are required for strength tests as the pipeline system must be proven to have adequate structural integrity. A RUPTURE during testing will force debris into the air which could cause damage or injury.

Rock size and the escape velocity of the fluid discharging from the RUPTURE are the two major factors dictating the maximum theoretical throw distance a rock could travel through the air. It is not dependent on total stored energy in the pipeline. Only the initial fraction of a second need be considered for a pneumatic test, as all remaining stored energy released for several hours after the RUPTURE will simply vent into the air, with the rocks and soil long gone.

2.1 Hydrostatic Testing

For hydrostatic testing, pipe diameter and wall thickness are also major factors which affect the maximum possible throw distances, along with rock size. The speed of sound in water is faster than it is in air whereas for pneumatic testing the escape velocity is always sonic regardless. The volume of compressed water to accelerate rocks during a RUPTURE is dependent on pipe diameter, wall thickness, material elasticity, hole size, the compressibility of water itself and the speed of decompression, which is a little less than the speed of sound in water. The speed of de-compression in water is approximately 1200 m/s. The methodology is best explained using a pipe 1200 metres long (i.e. 1 second long) as follows:

The water in a 1200 metre long pipe at zero pressure.



Additional (red) water added due to compression of the water and due to expansion of the pipe.

The distance the additional water travels in 1 second due to a full bore RUPTURE (red).

As an example, if this distance is 20 metres, then de-compression over 1 second corresponds to a fluid velocity of 20 metres per second. Water will also come from the opposite side of the rupture. If the RUPTURE cross sectional area is quite small, then the water will accelerate through the RUPTURE although its velocity cannot exceed that determined by Bernoulli's equation (½ ρ v2). The exit velocity is determined using energy balance equations. The smaller the hole, the faster the fluid.

For a hydraulic rupture, the jet of water is assumed to be a cylindrical shape, much like that of a fountain. The rock will continue on its trajectory after separating from the "fountain" of water but by then, it would have fully accelerated. Calculations show the rock accelerates to full speed within a very short distance. The final velocity is slightly slower than the water speed because of the rock's terminal velocity in water (the same as the free fall of a rock in a pond), which is of the order of 1 to 2 m/s, and because the water itself slows down as it climbs vertically.

Given the wide range of fluid velocities expected from different RUPTURE hole sizes, it is possible that a hydrostatic test with rock backfill and a small diameter RUPTURE could actually result in a larger throw distance than a pneumatic test.

2.2 Pneumatic Testing

For pneumatic testing, compressed air can only escape from a RUPTURE in a pipeline at sonic velocity. It is not possible for the escaping compressed air to be supersonic. This limits the maximum escape velocity for a projectile to be less than the speed of sound, which in turn dictates the maximum theoretical throw distance. In addition, rock size plays a major factor in how far a projectile will travel. Small sand grains will not travel very far due to air resistance, whereas rocks will cover a greater distance. A higher test pressure means larger rocks can be thrown whereas a low pressure test cannot accelerate large rocks.

Steel pipes tend to open to a full size RUPTURE given the crack speed developed (see photo below). However, this doesn't generally occur with HDPE piping since its crack propagation speed is much slower than what occurs in steel. As part of this Companion Paper, calculations have been performed for HDPE piping for a RUPTURE of 10% of the pipe diameter, as this is more consistent with observed failures in the field (see photos comparing steel and HDPE).



There is a limitation on the rock size which can be thrown with pneumatic testing. The combination of a small diameter pipeline and a large rock will result in a very limited maximum throw distance since the cross-sectional area of the pipeline rupture, which is the area pushing against the large rock, is much smaller than the cross-sectional area of the large rock itself.

For pneumatic testing analysis, step wise calculations were made to determine the maximum possible throw distances for different pipe size and rock size combinations (refer Section 6). The air escaping from the RUPTURE was modelled to expand in a conical shape at a ratio of 1:5, based on tests using a compressed air nozzle. The escaping air will continue at the speed of sound until its density is approximately the same as the surrounding air, at which point the flow will be subsonic. The drag coefficient of the rock, the air density at each point in the trajectory, and the rock density are all used for the calculations in both the X and Y directions, in order to determine the final trajectory for various rock sizes. These are summarised in Section 6 below.

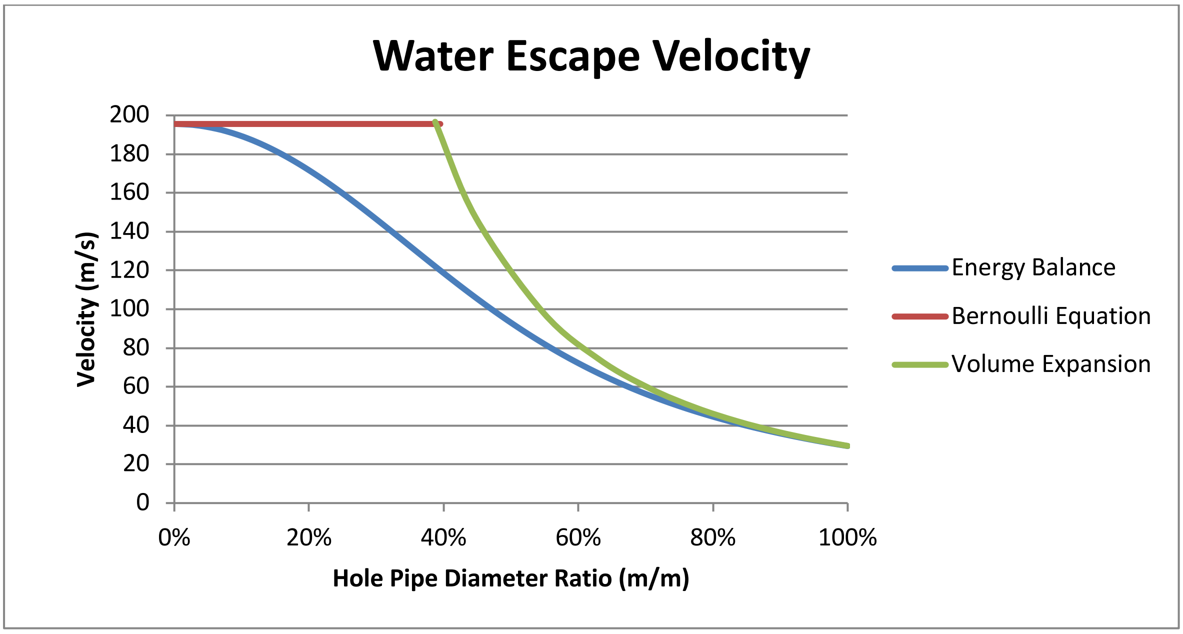
Drag coefficients for rocks vary. A perfectly smooth sphere is between 0.12 and 0.2 whereas a golf ball with its many indentations has a significantly higher drag coefficient of 0.35. Hail is approximately 0.5. Rocks which are more of an odd shape or rectangular shape would have a drag coefficient closer to that of the human body which is approximately 0.65. Therefore, a drag coefficient of 0.6 has been adopted as a reasonable value for typical rocks.

The calculations also show that the maximum possible throw distance is achieved with a RUPTURE at 42 degrees from the horizontal, rather than at 45 degrees. For PE pipes, a full diameter RUPTURE is very unlikely to occur, unlike steel pipes. A more likely failure for PE pipes is along the partial circumference of a weld or from mechanical damage.

Observed pipeline failures indicate that actual throw distances are approximately half the calculated theoretical maximum throw distances, since it is highly unlikely that all factors would be precise and optimum, and a rock would be in the exact location over the failure. Therefore, a risk based approach is required for determining exclusion zones rather than simply using the maximum possible throw distances as the final exclusion zone. Throw distances in high risk areas can be significantly reduced by backfilling the trench with sand and excluding all large rocks, as sand does not throw very far or cause significant damage if a RUPTURE were to occur. For non-high risk areas, the further any rocks in the trench are from the pipeline, the lower the possibility that the blast from a RUPTURE will perfectly align to achieve the maximum possible throw distance, so screened material is recommended. Provided all personnel are far enough away, a burst pipeline during a pressure test cannot cause any injury, although a pneumatic test failure is much more audible than a hydrostatic test. It is therefore valuable to determine maximum possible throw distances which can then be used to estimate practical exclusion zones, based on a risk assessment. The maximum possible throw distance is very unlikely to ever be achieved. There is a much higher probability that all rocks during a RUPTURE will fall well short of the maximum possible throw distance, and typically observed to be approximately half the maximum possible throw distance.

3 Hydrostatic Testing - Maximum Throw Distance

The following chart illustrates the expected escape velocities of water at different RUPTURE sizes, based on energy balance calculations. Note that the smaller the RUPTURE size, the higher the fluid velocity.



The following table lists typical values for Young's Modulus for HDPE. A value of 750 000 kPa has been used in this Companion Paper. The table assumes a medium range density for PE100.

PIPE *E* MATERIAL MODULUS FOR PE100			
Temp °C	PE 100- *E* Modulus (kPa x 10^3)		
	1h	2h	3h
5	**990**	**930**	**900**
10	**900**	**850**	**820**
15	**820**	**780**	**750**
20	**750**	**710**	**680**
25	**690**	**650**	**630**
30	**640**	**610**	**600**

For hydrotesting analysis, the decompression wave speed is first required and is calculated as follows:

$$\propto = \left[\frac{\rho}{K} + \frac{\rho D}{eE}\right]^{-0.5} \qquad 3(1)$$

where, α is de-compression wave speed, *ρ* is density of water, *K* is bulk modulus of water, *D* is pipe OD, *e* is wall thickness, *E* is Young's modulus.

The ratio *S* compares RUPTURE hole diameter and pipe diameter, and is used in several equations below. The worst case scenario is for a RUPTURE diameter equal to the maximum rock size.

$$S = \frac{d_h}{d_i} \qquad 3(2)$$

The fluid escape velocity through the RUPTURE hole reduces to the following equation:

$$v_{hole} = \frac{2S^2\left\{\propto - \sqrt{\propto^2 - \frac{P_i}{\rho}\left[2 - {}^{8}/_{S^4}\right]}\right\}}{S^4 - 4} \qquad 3(3)$$

where *Pi* is the initial test pressure before RUPTURE.

Initially, the rock velocity equals the fluid escape velocity minus its terminal velocity in water. The formula below is then used to calculate the terminal velocity of the rocks in the air after they have been accelerated:

$$v_t = \sqrt{\frac{2mg}{A\rho_{air}C_d}} \qquad 3(4)$$

where v_t is terminal velocity of rock in air, *m* is mass of the rock, *g* is gravity, *A* is cross sectional area of the rock, *ρ* is fluid density and C_d is the drag coefficient of the rock (estimated at 0.6).

The time the rock is in the air is calculated using the following equation, derived and integrated from first principles.

$$\mathrm{t} = \frac{v_t}{g}\left\{atan\left(\frac{v_y}{v_t}\right) + \operatorname{acosh}\left(\sqrt{1 + \frac{{v_y}^2}{{v_t}^2}}\right)\right\} \qquad 3(5)$$

The distance the rock will travel is calculated using the following integrated equation.

$$x_{max} = \frac{v_t^2}{g} ln\left(1 + \frac{tgv_x}{v_t^2}\right) \qquad 3(6)$$

The velocity of the rock in the horizontal and vertical planes, using a 42 degree angle, is:

$$v_x = v_{rock} cos(42) \qquad 3(7)$$

$$v_y = v_{rock} sin(42) \qquad 3(8)$$

3.1 Fluid escape velocity

In order to determine the maximum possible throw distance of rocks, the fluid escape velocity should first be calculated as follows:

For HYDROSTATIC TESTING, the decompression wave speed is first required. This is calculated as follows:

$$\propto = \left[\frac{\rho}{1000.K} + \frac{\rho D}{1000.t.E}\right]^{-0.5} \qquad ...3(1)$$

where

α	=	de-compression wave speed, in metres per second
ρ	=	density of water, in kilogram per cubic metre
K	=	bulk modulus of water, which is approximately 2,220,000 kilopascals
D	=	pipe outside diameter, in millimetres
t	=	wall thickness, in millimetres
E	=	Young's modulus, in kilopascals, which is approximately 750,000 kilopascals

The ratio S compares RUPTURE hole diameter and pipe internal diameter, where the hole diameter is never greater than the pipe internal diameter.

$$S = d_{hole} / D_{internal} \qquad ...3.(2)$$

The escape velocity for a liquid through the RUPTURE hole reduces to the following equation:

$$v_{hole} = \frac{2S^2\left\{\propto - \sqrt{\propto^2 - \frac{1000.P_S}{\rho}\left[2 - {}^8/_{S^4}\right]}\right\}}{S^4 - 4} \qquad ...3(3)$$

where

P_s = the initial test pressure before RUPTURE, in kilopascals.

The velocity of the rock is slightly less than the fluid escape velocity v_{hole} once losses and slowing of the fluid as it rises are both taken into account. This combination is of the order of 2 to 5m/s in water and tens of metres per second in compressed air depending on the density of the air.

The following may be helpful in the projectile range estimation and its influence on the EXCLUSION ZONE:

(i) A RUPTURE below the pipe centreline will result in a significantly smaller throw distance than at the 10 or 2 o'clock position.

(ii) A RUPTURE at the 12 o'clock position will not achieve a significant horizontal throw distance.

Pipeline failures investigated in the past have actual throw distances approximately half those of the maximum throw distances calculated here, although rock sizes and RUPTURE locations have not been recorded, so it is difficult to correlate.

Initially, the rock velocity in a HYDROSTATIC TEST is close to the fluid escape velocity. Once air borne, the terminal velocity of a rock in air is calculated using the following equation, which is applicable for both pneumatic and HYDROSTATIC TESTS:

$$v_t = \sqrt{\frac{2mg}{A.\rho_{air}C_d}} \qquad \text{...3.(4)}$$

where

v_t	=	terminal velocity of the rock in air, in metres per second
m	=	mass of the rock, in kilograms
g	=	gravity, in metres per second squared
A	=	cross sectional area of the rock, in square metres
ρ_{air}	=	the density of air, in kilograms per cubic metre
C_d		the drag coefficient of the rock (typically about 0.6)

The time the rock is in the air is calculated using the following equation (*where* atan *is in radians*):

$$t_{air} = \frac{v_t}{g}\left\{atan\left(\frac{v_y}{v_t}\right) + \text{acosh}\left(\sqrt{1+\frac{{v_y}^2}{{v_t}^2}}\right)\right\} \qquad \text{...3.(5)}$$

where:

v_y = the velocity of the rock in the vertical plane using the worst-case orientation of 42 degrees.

Therefore $v_y = v_{rock}\sin(42)$, in metres per second

For the horizontal plane, $v_x = v_{rock}\cos(42)$, in metres per second

The maximum distance a rock can possibly be thrown is calculated using the following equation:

$$x_{max} = \frac{v_t^2}{g} ln\left(1+\frac{t_{air}gv_x}{v_t^2}\right) \qquad \text{...3.(6)}$$

where

t_{air} = the time the rock is in the air, in seconds

For pipelines buried at a significant depth (e.g. road, rail and HDD crossings), the weight of the soil above the pipeline can be enough to prevent projectiles. The required depth depends on the soil type. For sand, a slightly tapered cylindrical shape can be considered for calculations whereas for clay, a wider inverted cone would be applicable. As a guide, for a pressure test of 2000 kPa, a depth beyond 10 m in sand, and a depth beyond 3 m in clay is likely to prevent a crater being formed as a result of a RUPTURED pipe. Depth is dependent on soil type, water content and compaction. Consideration should be given for PRELIMINARY TESTING of crossings at critical locations before installation.

3.2 Hydrostatic Testing Worked Example

As an example, a HYDROSTATIC TEST of a PE100, SDR 11, DN355 pipeline is required. The test pressure is 2000 kPa. Young's modulus is 750 000kPa. The Bulk Modulus of water is 2 220 000kPa. The pipe outside diameter is 355mm and the wall thickness is 32.2mm.

The decompression wave speed of the water in the pipe is:

$$\alpha = \left[\frac{\rho}{1\,000.K} + \frac{\rho D}{1\,000.t.E} \right]^{-0.5} \quad \text{...3(1)}$$

$=[1\,000 / (1\,000 \times 2\,200\,000) + 1\,000 \times 355 / (1\,000 \times 32.2 \times 750\,000)]^{-0.5}$

$= 256.9$ m/s

The worst-case scenario for a HYDROSTATIC TEST tends to be a RUPTURE between 20 % and 40 % of the pipe diameter. However, HDPE ruptures are generally significantly smaller than this, so a 10% case has been assumed (RUPTURE size of 10% of the pipe diameter).

The fluid escape velocity v_{hole} is

$$v_{hole} = \frac{2S^2 \left\{ \alpha - \sqrt{\alpha^2 - \frac{1\,000.P_s}{\rho}[2 - 8/S^4]} \right\}}{S^4 - 4} \quad \text{.....3(3)}$$

$= 2 \times (10\%)^2 \times \{256.9 - \sqrt{(256.9^2 - 1000 \times 2000 / 1000 \times [2 - 8/(10\%)^4]\ )}\ \} / (10\%^4 - 4)$

$= 62$ m/s

A reasonable estimate for the maximum possible velocity of a rock v_{rock} entrained by this jet is approximately 60 m/s, allowing for minor losses and for the reduced jet velocity as the jet of water rises into the air over the first metre or so until the rock is fully accelerated.

Rocks of different sizes are expected in the backfill. Their density is 1 850 kg/m^3. The drag coefficient assumed for the calculation is 0.6. Assuming a rock of 40mm in size, the mass is 0.062 kg and its cross sectional area is 0.00126 m^2.

The maximum velocity of a rock (v_{rock}) as it leaves the RUPTURE was estimated above to be 60m/s, based on a fluid velocity of 62m/s.

The terminal velocity of a 40mm rock in air is

$$v_t = \sqrt{\frac{2mg}{A.\rho_{air} C_\mathrm{d}}} \quad \text{....3.(4)}$$

= √ [2 x 0.062 x 9.81 / (0.00126 x 1.2 x 0.6)]

= 36.7 m/s

The vertical COMPONENT of the velocity of the rock as it leaves the RUPTURE is

$$v_\mathrm{y} = v_{rock} \sin(42) \quad \text{....3(8)}$$

= 60 x 0.67

=40.2 m/s

The horizontal COMPONENT of the velocity of the rock as it leaves the RUPTURE is

$$v_x = v_{rock} \cos(42) \quad \text{....3(7)}$$

= 60 x .74

= 44.4 m/s

The time the 40mm rock is in the air is:

$$\mathrm{t}_{\mathrm{air}} = \frac{v_t}{g} \{atan\left(\frac{v_y}{v_t}\right) + \mathrm{acosh}\left(\sqrt{1 + \frac{v_y{}^2}{v_t{}^2}}\right)\} \quad \text{......3(5)}$$

= 41 / 9.81 x { atan (40.2 / 36.7) + acosh (√ [1 + 40.2^2 / 36.7^2]) }

= 6.7 seconds

The maximum possible throw distance for a 40mm rock is

$$\boxed{x_{max} = \frac{v_t^2}{g} ln\left(1 + \frac{tgv_x}{v_t^2}\right)} \quad \text{...3(6)}$$

= 36.7^2 / 9.81 x ln { 1 + (6.7 x 9.81 x 44.4) / 36.7^2 }

= 157 metres

Repeating the calculations above for 10mm, 20mm, 80mm, and 160mm rocks, and assuming an approximately spherical rock shape, the mass, area, and terminal velocity of each rock size are as follows:

	mass kg	cross sectional area m2	terminal velocity m/s	time in the air s	max throw distance m
Stone (10mm)	0.001	0.00008	18.3	5	69
Stone (20mm)	0.0077	0.00031	25.9	5.9	108
Rock (40mm)	0.062	0.00126	36.7	6.7	157
Rock (80mm)	0.496	0.00503	51.9	7.3	213
Rock (160)	3.968	0.02011	73.3	7.7	265

The probability of rocks reaching these maximum throw distances is very low. Rocks larger than the RUPTURE size are particularly unlikely, as they would essentially need to balance at the exact centre of the stream to be projected fully. In this example, the 80mm and 160mm rocks are in this category as they are much larger than the RUPTURE hole.

Based on RUPTURES investigated in the past, actual throw distances could be approximately half of the maximum possible throw distances.

4 Pneumatic Testing - Maximum Throw Distance

The charts in Section 6 below summarise the theoretical maximum possible throw distances for PE100 pipes of all diameters and SDR's. Note that the test pressure, rather than the SDR, is the main factor influencing the curves on the charts. Therefore, if a lower test pressure is planned, it is permissible to interpolate using the applicable lower pressure chart (with its different SDR) to evaluate the maximum possible throw distance. The charts have been derived using stepwise Excel calculations at fractions of a second apart, for a hole size of 10% of pipe ID. Given a full bore RUPTURE is deemed as very unlikely and observed ruptures are comparatively small, the 10% case has been considered as the most credible option. As a comparison, RUPTURE hole sizes of 25%, 50% and 100% result in approximately, 150%. 200% and 300% larger throw distances respectively. The charts in Section 7 for full bore ruptures have been included for information, so comparisons can be made with the more likely 10% case.

For PNEUMATIC TESTING, the escape velocity of the fluid is sonic (i.e. approximately 340 m/s for air). Therefore the maximum possible velocity of a rock v_{rock} being propelled from a RUPTURE can be no greater than sonic (340 m/s) minus its terminal velocity in air. Maximum rock velocity estimates range from 95% of sonic for sand (320 m/s) through to 60% of sonic velocity for large rocks (200 m/s). This is allowing for the compressed air jet expanding at a ratio of 1:5 until it is no longer sonic.

4.1 Pneumatic Testing Worked Example

As an example, a PNEUMATIC TEST of a PE100, SDR 11, DN355 pipeline is required. The test pressure is 2000 kPa. The pipe outside diameter is 355mm and the wall thickness is 32.2mm. A RUPTURE hole size of 10% is assumed. The backfill was not screened during construction so all rock sizes are assumed to be present.

Using the chart below in Section 6 for SDR 11 pipe with a diameter of 355mm, the maximum possible throw distances for different sized rocks are as follows:

Sand – 30m

Small stones (10mm) – 93m

Large stones (20mm) – 132m

Small rocks (40mm) – 147m

Large rocks (80mm) – 81m

Very large rocks (160mm) – 19m

The worst case rock size for this particular failure is 40mm rocks, with a maximum possible throw distance of 147m.

Near a country town, screening was used during backfilling of the trench, screening out anything larger than 10mm. Using the applicable chart in Section 6, the maximum possible throw distance is 93 metres for 10mm stones. The exclusion zone for this section near the country town can therefore be reduced.

Down the main street of the town, imported sand was used for the backfill. Using the chart, the maximum possible throw distance is 30 metres for sand. Therefore, the exclusion zone for this section can be significantly reduced, especially since sand will not cause injuries like rocks will.

5 Summary of Hydrostatic Testing and Pneumatic Testing Example

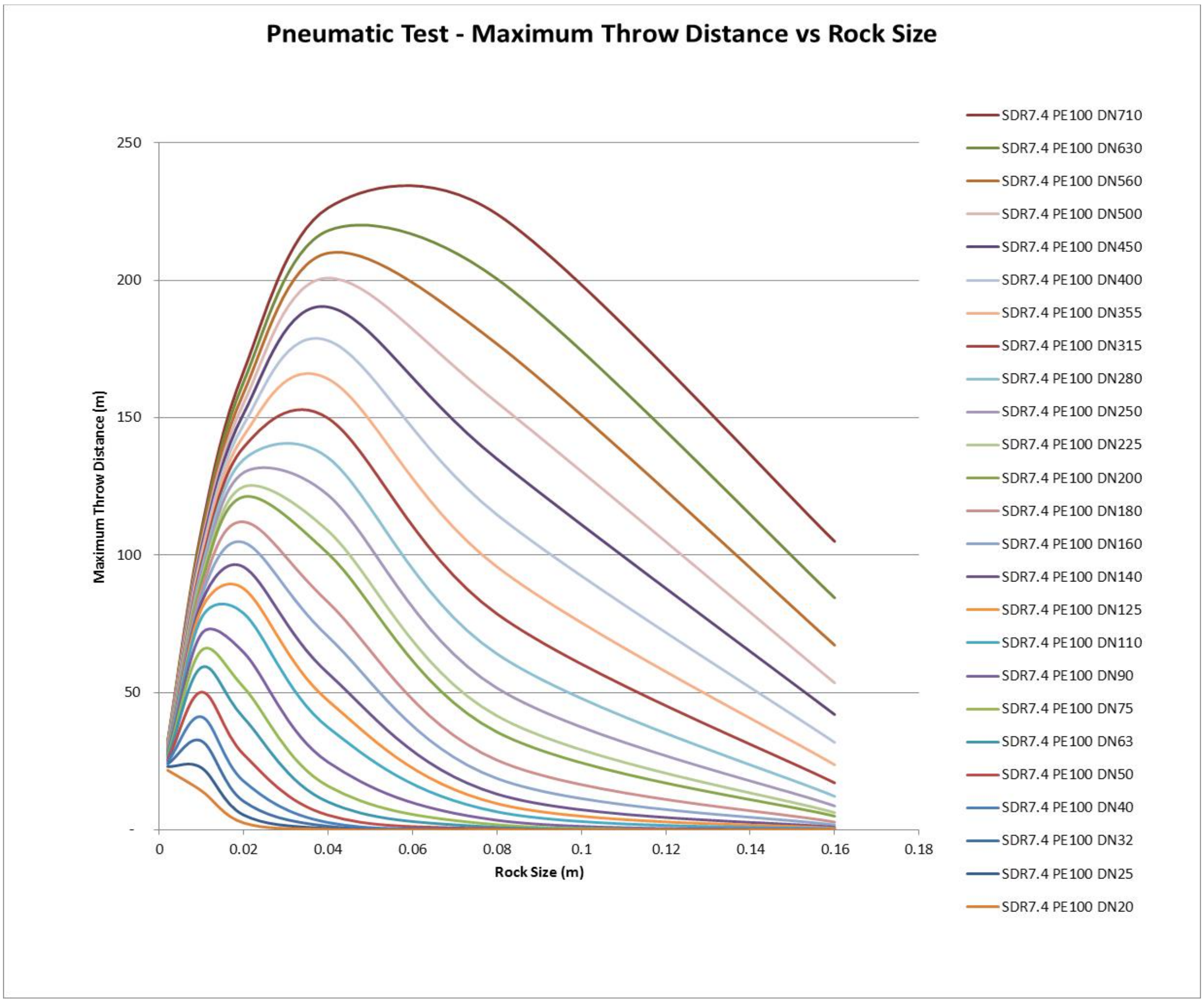
The results for both the hydrostatic test and the pneumatic test in the worked examples above are summarised:

	Maximum possible throw distance using a hydrostatic test (m)	Maximum possible throw distance using a pneumatic test (m)
Sand (2mm)	21	30
Stone (10mm)	69	93
Stone (20mm)	108	132
Rock (40mm)	157	147
Rock (80mm)	213	81
Rock (160)	265	19

In this example, the throw distances for small rocks are approximately 50% further for the pneumatic test. However, the results show that a hydrostatic test could potentially throw the large rocks further than a pneumatic test could do. Therefore it cannot always be assumed that a hydrotest is safer than a pneumatic test. It can be possible for a hydrostatic test to require a larger exclusion zone than a pneumatic test, because of the size of rocks in the backfill. This is because throw distances are dependent on both fluid velocity and rock size, and not on stored energy. While the velocity of the water from the RUPTURE is slower than that of air, the water can fully accelerate a large rock, whereas compressed air would not. The escaping air from a small hole cannot accelerate a large rock like water can. In order to achieve large throw distances of large rocks using compressed air, a large RUPTURE hole is required, like a full bore rupture. However, while full bore ruptures are normally seen in steel pipeline failures, it is very unlikely for them to occur in HDPE pipeline failures. Therefore, for HDPE pipelines, it is possible that a larger exclusion zone could be required when using water than when using compressed air. It is therefore encouraged to perform calculations as shown in this Companion Paper, considering rock sizes in the backfill, when assessing the risk of a selected exclusion zone and test fluid.

6 Maximum Throw Distance Charts for Pneumatic Testing Using 10% Hole Size

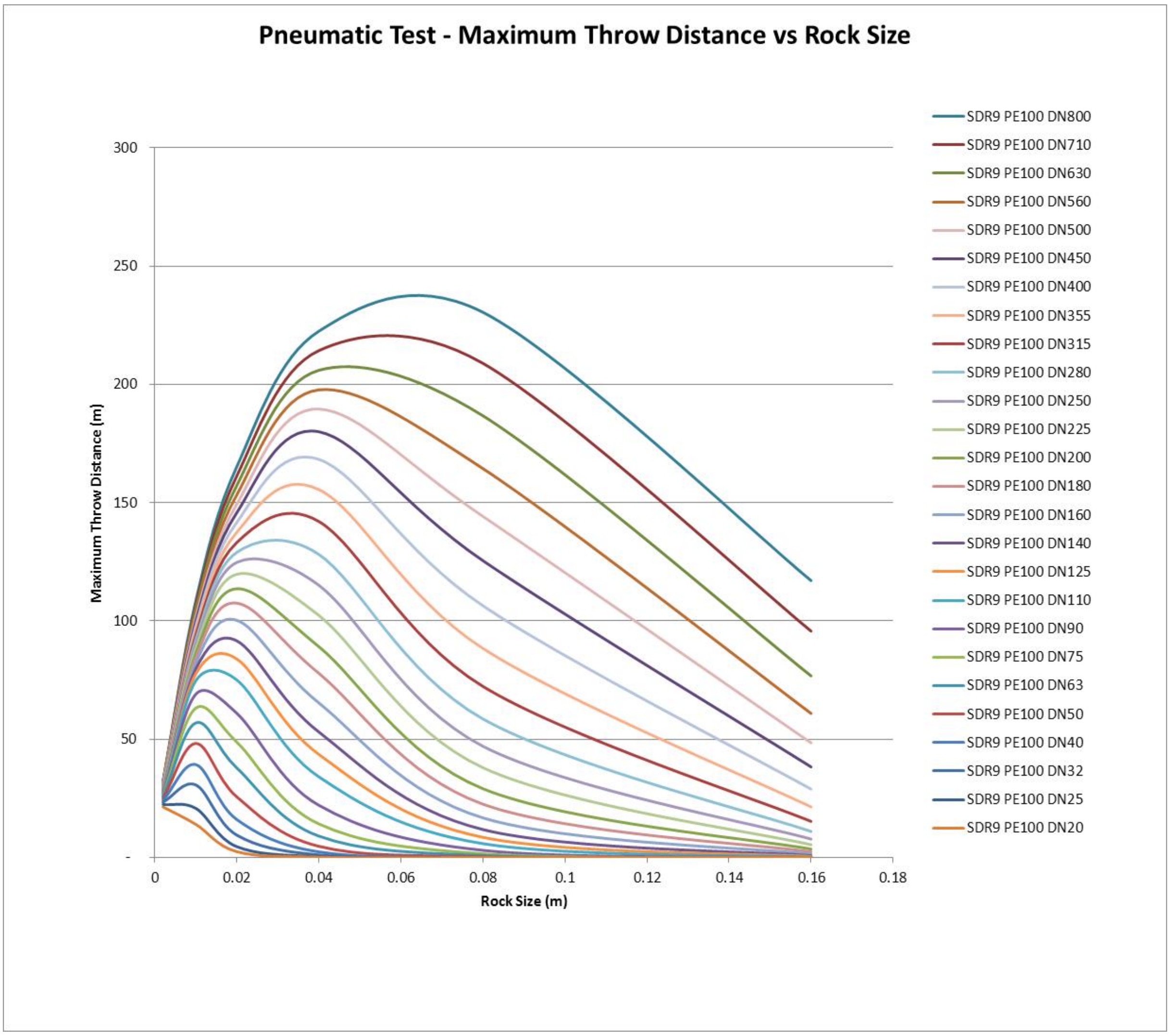
SDR 7.4 PE100. at Test Pressure of 3.125 MPa (10% hole size case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180
TRENCH BACKFILL													
Sand (2 mm)	22	23	24	25	25	26	27	27	28	28	29	29	29
Stones (10 mm)	14	23	32	41	50	59	65	71	77	80	83	85	87
Stones (20 mm)	3	5	10	18	27	41	52	65	79	88	96	105	112
Rocks (40 mm)	0	1	1	3	5	10	16	25	37	47	57	70	83
Rocks (80 mm)	0	0	0	0	0	1	2	4	7	10	13	19	25
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	1	1	2	3

	DN200	DN225	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	
TRENCH BACKFILL													
Sand (2 mm)	30	30	30	30	31	31	31	31	32	32	32	32	
Stones (10 mm)	90	91	93	95	97	99	101	102	104	106	108	109	
Stones (20 mm)	121	125	130	135	139	143	148	152	155	159	163	167	
Rocks (40 mm)	101	109	122	135	150	164	178	190	201	210	218	226	
Rocks (80 mm)	36	42	52	64	79	96	115	135	156	177	201	224	
Rocks (160 mm)	5	6	9	12	17	24	32	42	54	67	84	105	

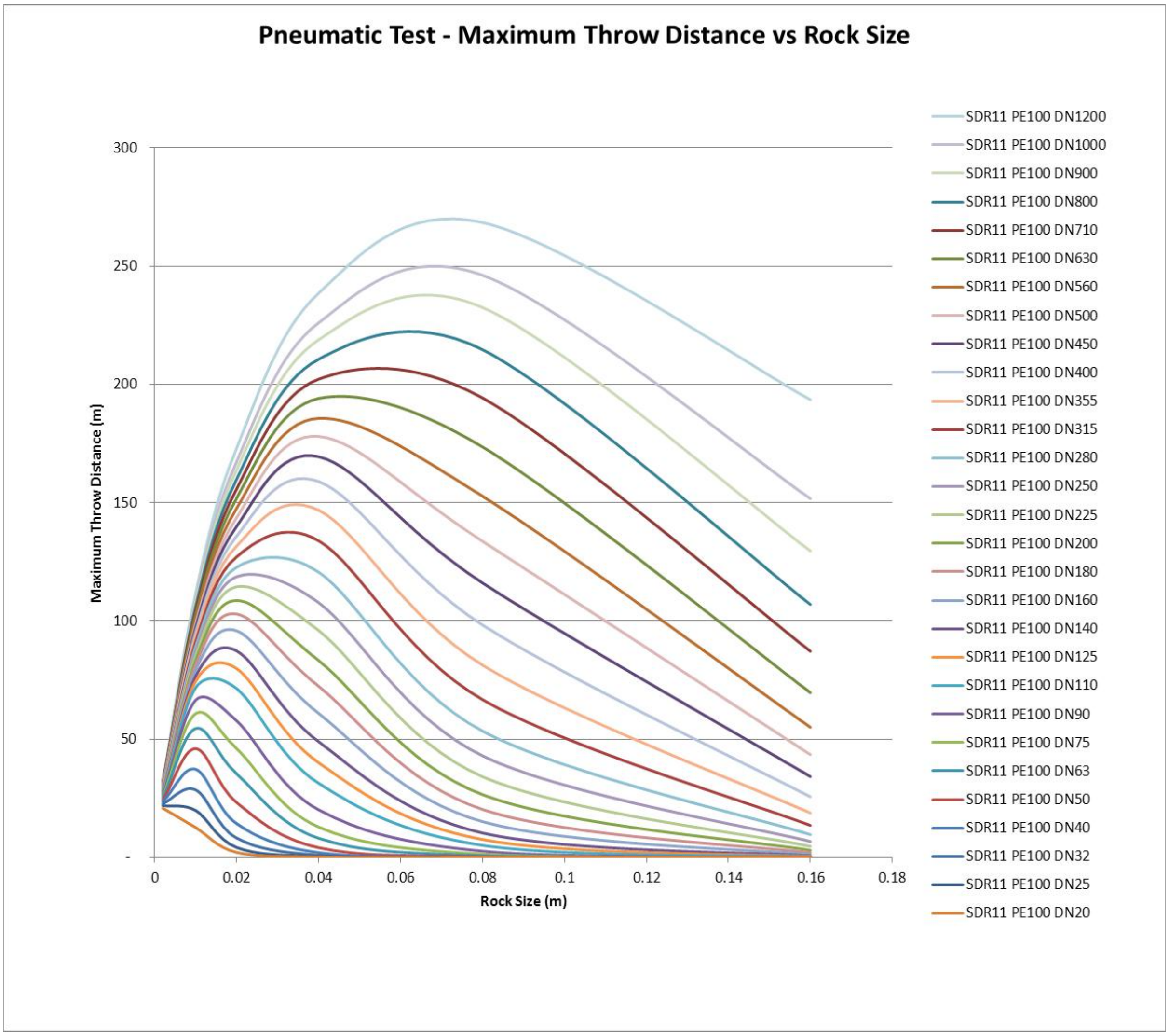
SDR 9 PE100. at Test Pressure of 2.5 MPa (10% hole size case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180
TRENCH BACKFILL													
Sand (2 mm)	21	22	23	24	25	26	26	27	27	28	28	28	29
Stones (10 mm)	14	21	31	39	48	57	63	69	75	78	80	82	84
Stones (20 mm)	3	5	9	16	26	38	49	61	75	84	92	100	108
Rocks (40 mm)	0	0	1	2	5	9	14	22	34	44	53	65	78
Rocks (80 mm)	0	0	0	0	0	1	2	3	6	9	12	17	23
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	1	2	2

	DN200	DN225	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800
TRENCH BACKFILL													
Sand (2 mm)	29	29	30	30	30	31	31	31	31	31	32	32	32
Stones (10 mm)	86	88	90	92	94	96	98	100	101	103	105	107	109
Stones (20 mm)	114	120	125	129	133	138	142	146	149	153	157	161	165
Rocks (40 mm)	89	102	115	128	142	156	168	180	190	198	206	214	223
Rocks (80 mm)	29	38	47	59	72	88	106	126	144	164	187	209	231
Rocks (160 mm)	4	5	8	11	15	21	29	38	48	61	77	96	117

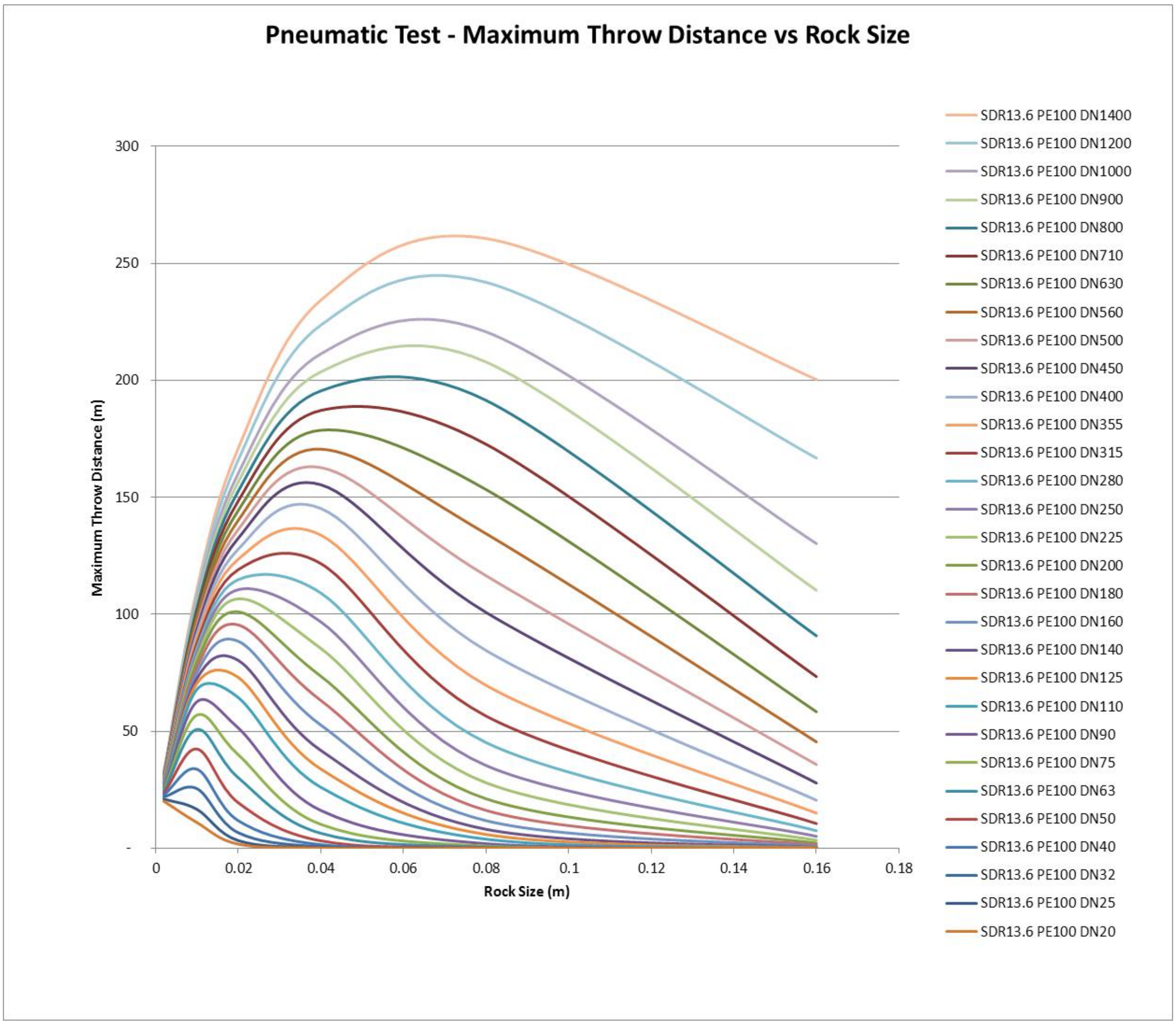
SDR 11 PE100 at Test Pressure of 2 MPa (10% case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	21	22	23	24	24	25	26	26	27	27	28	28	28	29	29
Stones (10 mm)	13	20	29	37	46	55	61	67	72	74	77	79	81	83	85
Stones (20 mm)	2	4	8	14	23	35	46	58	71	80	87	96	103	109	114
Rocks (40 mm)	0	0	1	2	4	8	13	20	31	40	49	61	72	83	96
Rocks (80 mm)	0	0	0	0	0	1	1	3	5	8	10	15	20	27	34
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	1	1	2	3	5

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	
TRENCH BACKFILL															
Sand (2 mm)	29	30	30	30	30	31	31	31	31	32	32	32	32	33	
Stones (10 mm)	87	89	91	93	95	97	99	101	102	104	106	108	109	112	
Stones (20 mm)	119	123	127	132	136	140	144	148	152	156	160	164	167	173	
Rocks (40 mm)	108	121	134	147	159	169	178	186	194	202	211	219	226	239	
Rocks (80 mm)	43	53	67	81	98	116	134	153	174	194	215	233	246	268	
Rocks (160 mm)	7	10	14	19	26	34	44	55	70	87	107	130	152	194	

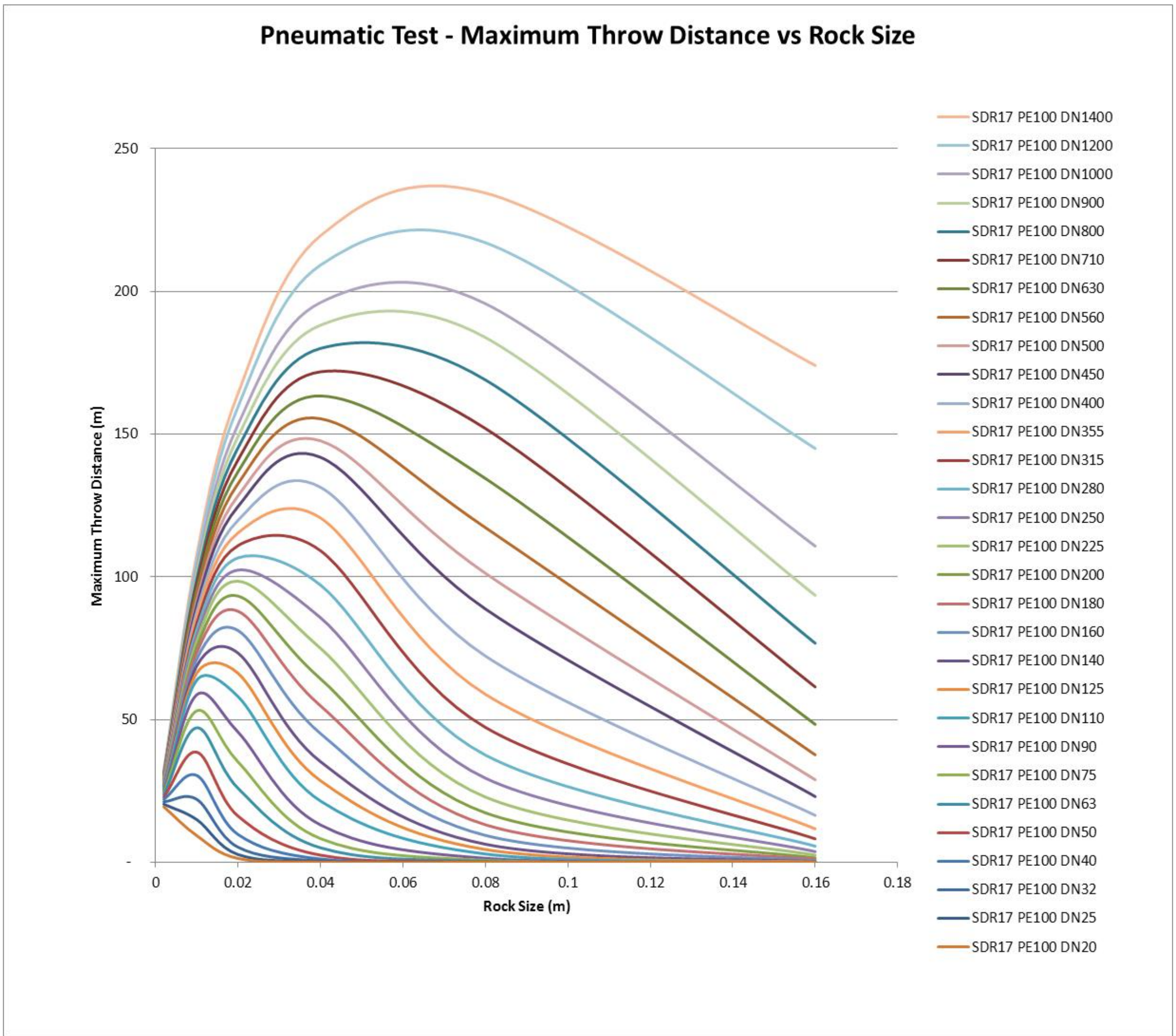
SDR 13.6 PE100 at Test Pressure of 1.588 MPa (10% case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	20	21	22	23	24	24	25	26	26	27	27	27	28	28	28
Stones (10 mm)	11	17	26	34	42	51	57	63	68	71	73	75	77	80	82
Stones (20 mm)	2	3	7	12	20	30	40	51	64	73	80	89	96	101	107
Rocks (40 mm)	0	0	1	2	3	6	10	16	26	34	42	53	63	74	85
Rocks (80 mm)	0	0	0	0	0	0	1	2	4	6	8	12	16	21	28
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	DN1400
TRENCH BACKFILL															
Sand (2 mm)	29	29	29	30	30	30	30	31	31	31	31	32	32	32	32
Stones (10 mm)	83	86	88	90	92	94	95	97	99	101	103	104	106	109	111
Stones (20 mm)	111	115	119	124	128	133	136	140	144	148	153	157	160	166	171
Rocks (40 mm)	97	109	122	134	145	155	163	171	179	187	196	204	211	224	234
Rocks (80 mm)	35	45	57	70	85	101	117	134	153	173	191	208	221	242	261
Rocks (160 mm)	5	8	11	15	21	28	36	46	58	73	91	110	130	167	200

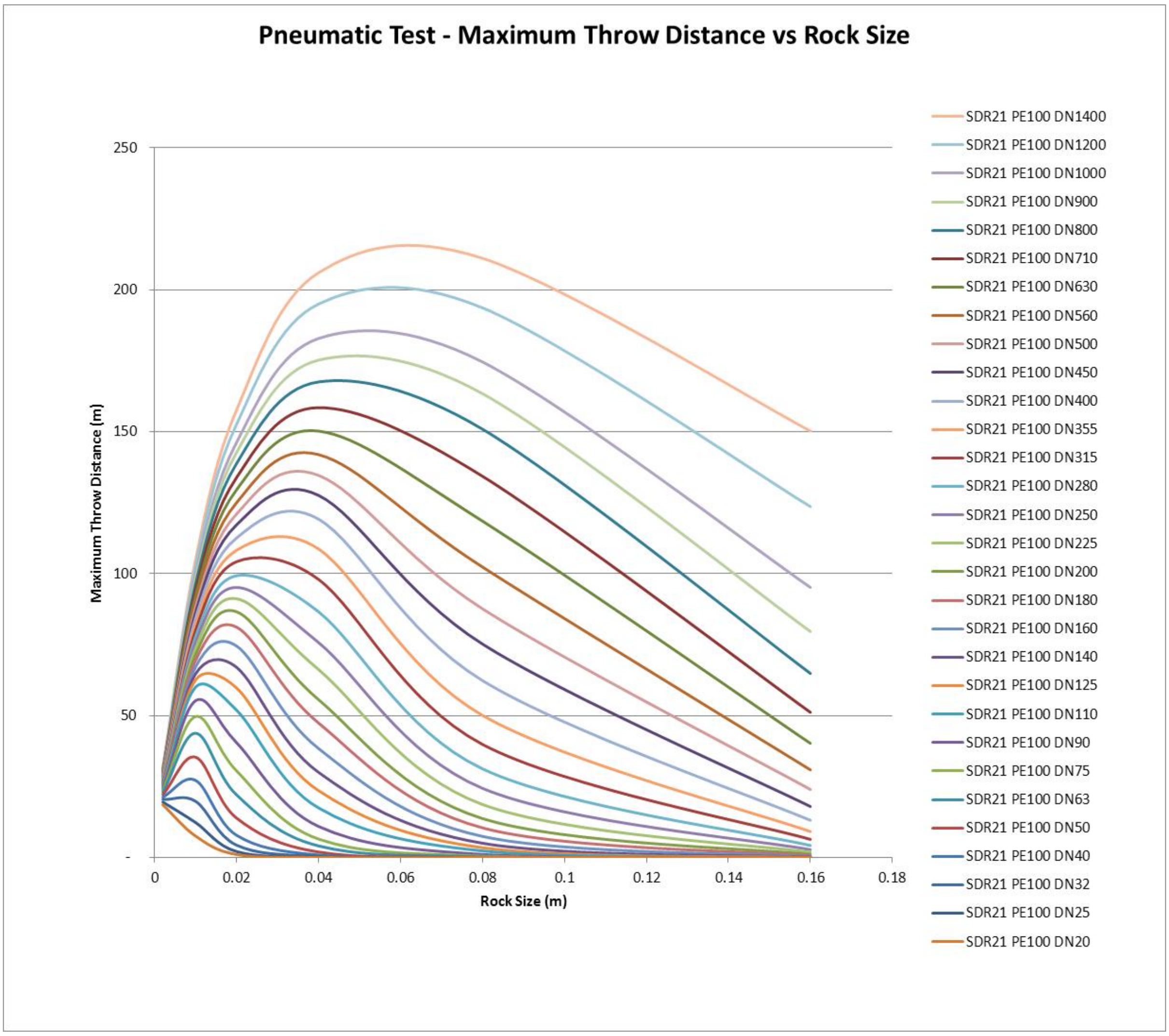
SDR 17 PE100 at Test Pressure of 1.25 MPa (10% case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	19	20	21	22	23	24	24	25	26	26	26	27	27	27	28
Stones (10 mm)	9	15	22	30	39	47	53	59	64	66	69	71	74	75	78
Stones (20 mm)	1	3	5	10	16	26	35	46	58	66	73	81	88	93	98
Rocks (40 mm)	0	0	1	1	3	5	8	13	22	29	35	45	55	64	75
Rocks (80 mm)	0	0	0	0	0	0	1	1	3	5	6	9	13	17	23
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	DN1400
TRENCH BACKFILL															
Sand (2 mm)	28	28	29	29	29	30	30	30	30	31	31	31	31	32	32
Stones (10 mm)	79	82	84	86	88	90	92	94	95	97	99	101	103	106	108
Stones (20 mm)	102	107	111	115	120	125	128	133	137	141	145	149	153	160	164
Rocks (40 mm)	86	97	109	121	131	142	148	155	163	172	180	188	196	209	220
Rocks (80 mm)	29	38	47	59	72	89	101	117	134	152	169	184	196	217	234
Rocks (160 mm)	4	6	8	12	16	23	29	38	48	61	77	94	111	145	174

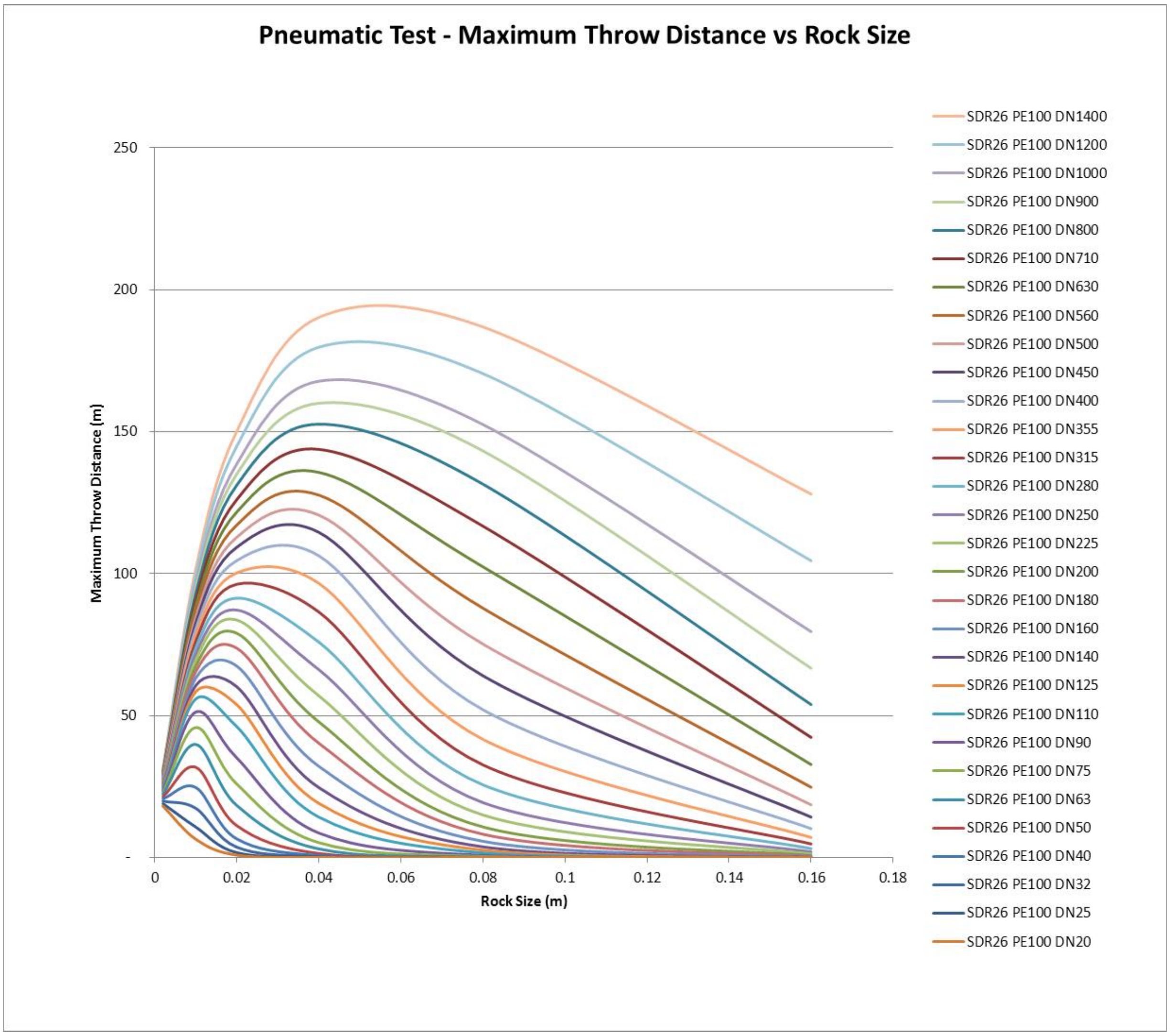
SDR 21 PE100 at Test Pressure of 1 MPa (10% case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	19	20	20	21	22	23	24	24	25	25	26	26	26	27	27
Stones (10 mm)	8	12	20	27	35	44	50	55	60	63	65	67	70	72	74
Stones (20 mm)	1	2	4	8	14	22	31	40	52	60	67	75	81	87	91
Rocks (40 mm)	0	0	0	1	2	4	7	11	17	24	30	38	47	56	66
Rocks (80 mm)	0	0	0	0	0	0	1	1	2	3	5	7	10	14	19
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	DN1400
TRENCH BACKFILL															
Sand (2 mm)	27	28	28	28	29	29	29	30	30	30	31	31	31	31	32
Stones (10 mm)	76	78	80	82	84	86	88	90	92	94	97	98	100	103	105
Stones (20 mm)	95	99	104	108	113	117	121	125	130	134	139	143	146	153	158
Rocks (40 mm)	76	87	98	109	119	128	135	142	150	159	168	175	183	195	206
Rocks (80 mm)	24	31	40	50	62	75	88	102	119	134	151	163	175	194	211
Rocks (160 mm)	3	4	6	9	13	18	24	31	40	51	65	80	95	124	150

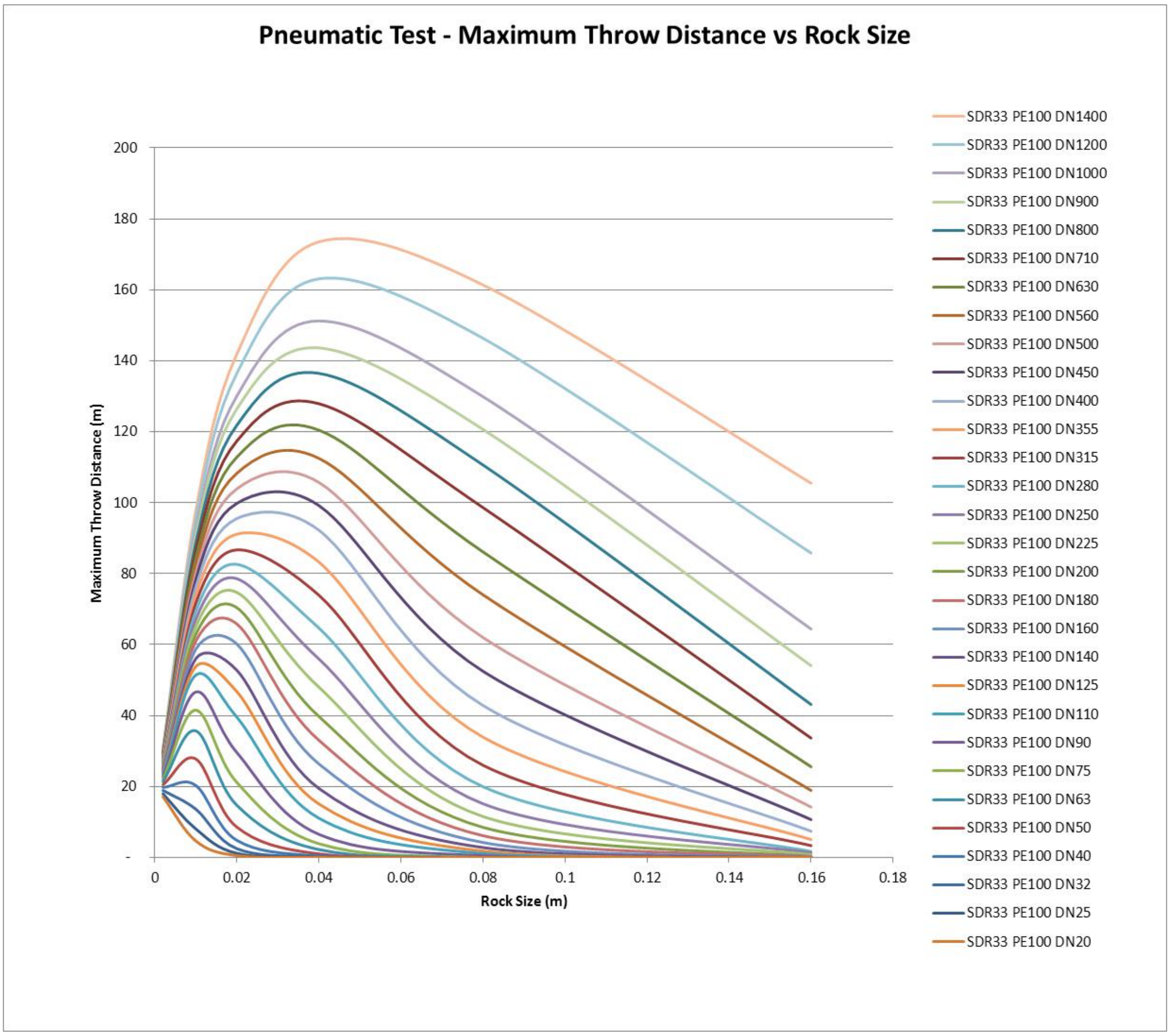
SDR 26 PE100 at Test Pressure of 800 kPa (10% case).



	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	18	19	20	21	21	22	23	24	24	25	25	25	26	26	26
Stones (10 mm)	6	11	17	25	32	40	46	51	56	58	61	63	66	67	70
Stones (20 mm)	1	2	4	7	11	18	26	35	46	54	60	67	74	79	84
Rocks (40 mm)	0	0	0	1	1	3	5	9	14	19	25	32	40	48	57
Rocks (80 mm)	0	0	0	0	0	0	0	1	2	3	4	6	8	11	15
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	DN1400
TRENCH BACKFILL															
Sand (2 mm)	27	27	28	28	28	29	29	29	29	30	30	30	31	31	31
Stones (10 mm)	72	74	76	78	81	83	84	87	89	91	93	95	97	99	102
Stones (20 mm)	87	91	96	100	105	109	113	117	122	126	131	135	139	145	150
Rocks (40 mm)	66	76	87	97	106	115	121	128	136	144	153	160	168	180	190
Rocks (80 mm)	19	26	33	42	52	64	75	88	102	117	132	143	153	170	187
Rocks (160 mm)	2	3	5	7	10	14	19	25	33	42	54	67	80	105	128

SDR 33 PE100 at Test Pressure of 625 kPa (10% case).



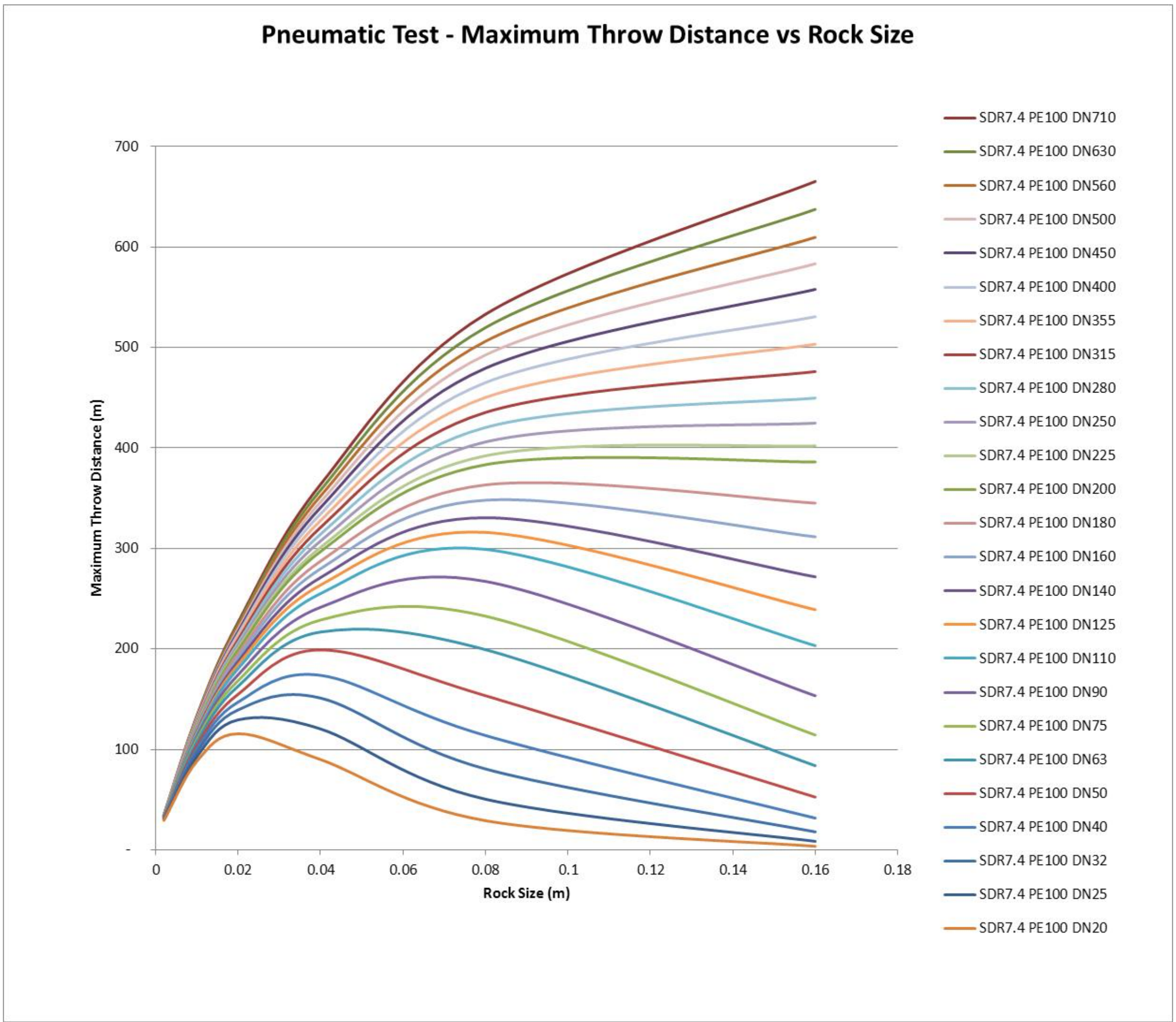
	DN20	DN25	DN32	DN40	DN50	DN63	DN75	DN90	DN110	DN125	DN140	DN160	DN180	DN200	DN225
TRENCH BACKFILL															
Sand (2 mm)	17	18	19	20	21	21	22	23	23	24	24	25	25	25	26
Stones (10 mm)	5	8	14	20	28	36	42	47	51	54	56	59	61	63	65
Stones (20 mm)	1	1	3	5	9	15	21	30	40	47	53	60	66	70	75
Rocks (40 mm)	0	0	0	0	1	2	4	7	11	15	19	26	33	40	48
Rocks (80 mm)	0	0	0	0	0	0	0	1	1	2	3	4	6	9	12
Rocks (160 mm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

	DN250	DN280	DN315	DN355	DN400	DN450	DN500	DN560	DN630	DN710	DN800	DN900	DN1000	DN1200	DN1400
TRENCH BACKFILL															
Sand (2 mm)	26	26	27	27	27	28	28	28	29	29	29	30	30	30	31
Stones (10 mm)	67	69	72	74	76	78	80	82	84	86	89	91	92	95	98
Stones (20 mm)	79	83	87	91	96	100	104	108	113	117	122	126	130	136	142
Rocks (40 mm)	56	65	74	83	92	99	106	113	120	128	136	144	151	163	174
Rocks (80 mm)	15	20	26	34	43	53	62	74	86	99	111	121	130	146	161
Rocks (160 mm)	1	2	3	5	7	11	14	19	26	34	43	54	64	86	106

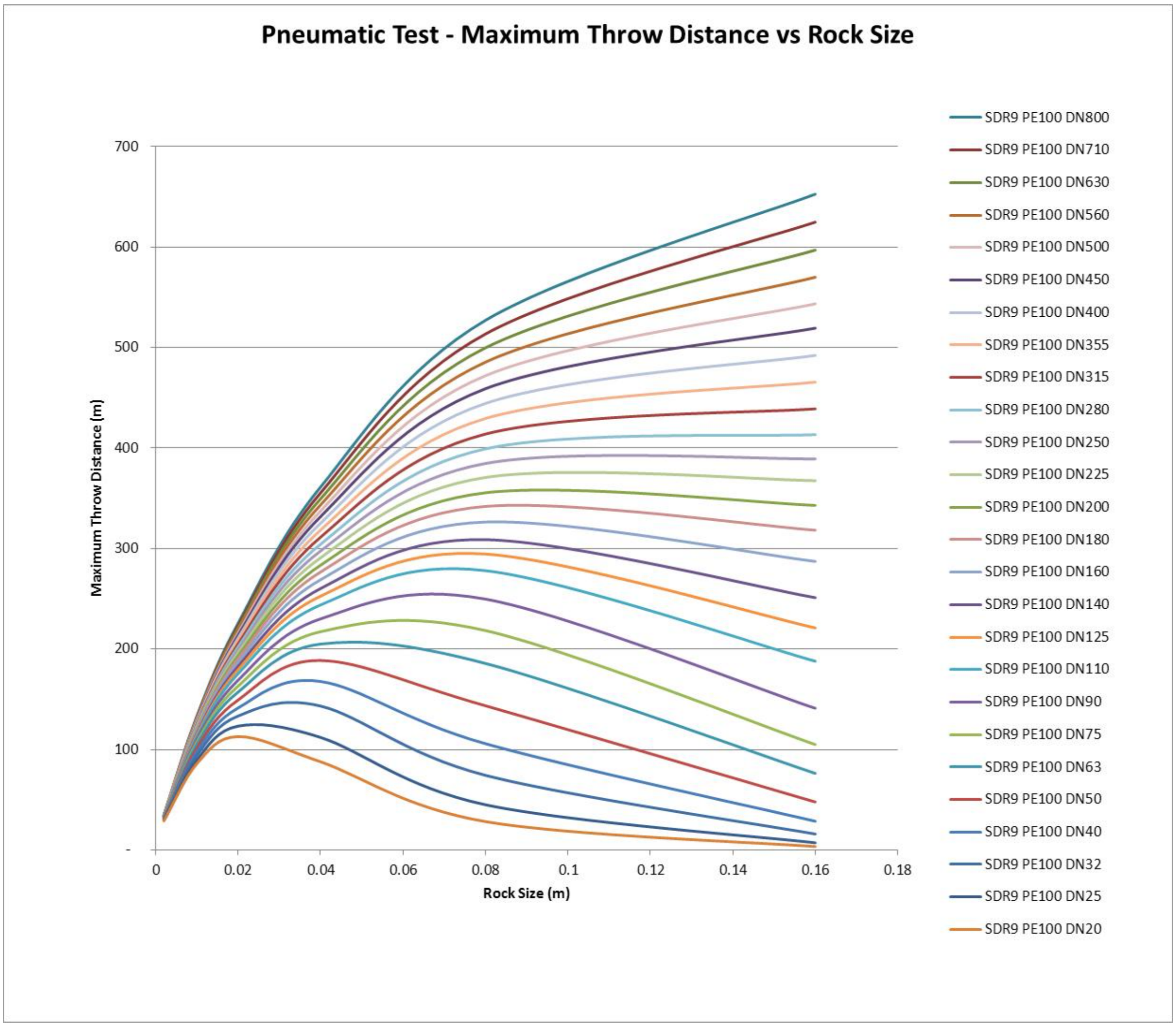
7 Maximum Throw Distance Charts for Pneumatic Testing – Full Bore Rupture

A full bore RUPTURE for HDPE piping is very unlikely. These charts have been included for information purposes, so comparisons can be made with the more likely 10% hole-size case.

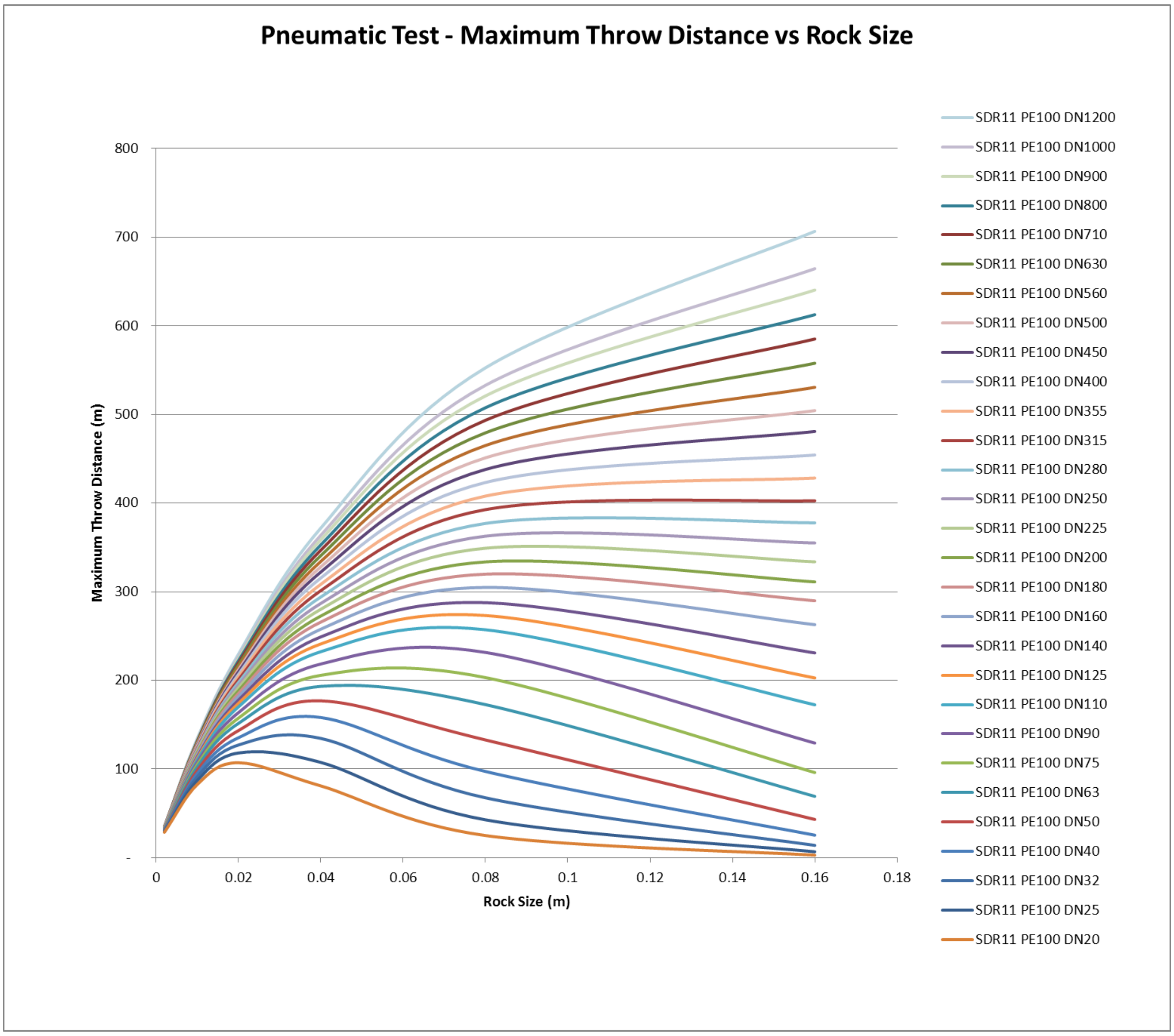
SDR 7.4 PE100. at Test Pressure of 3.125 MPa (full bore rupture).



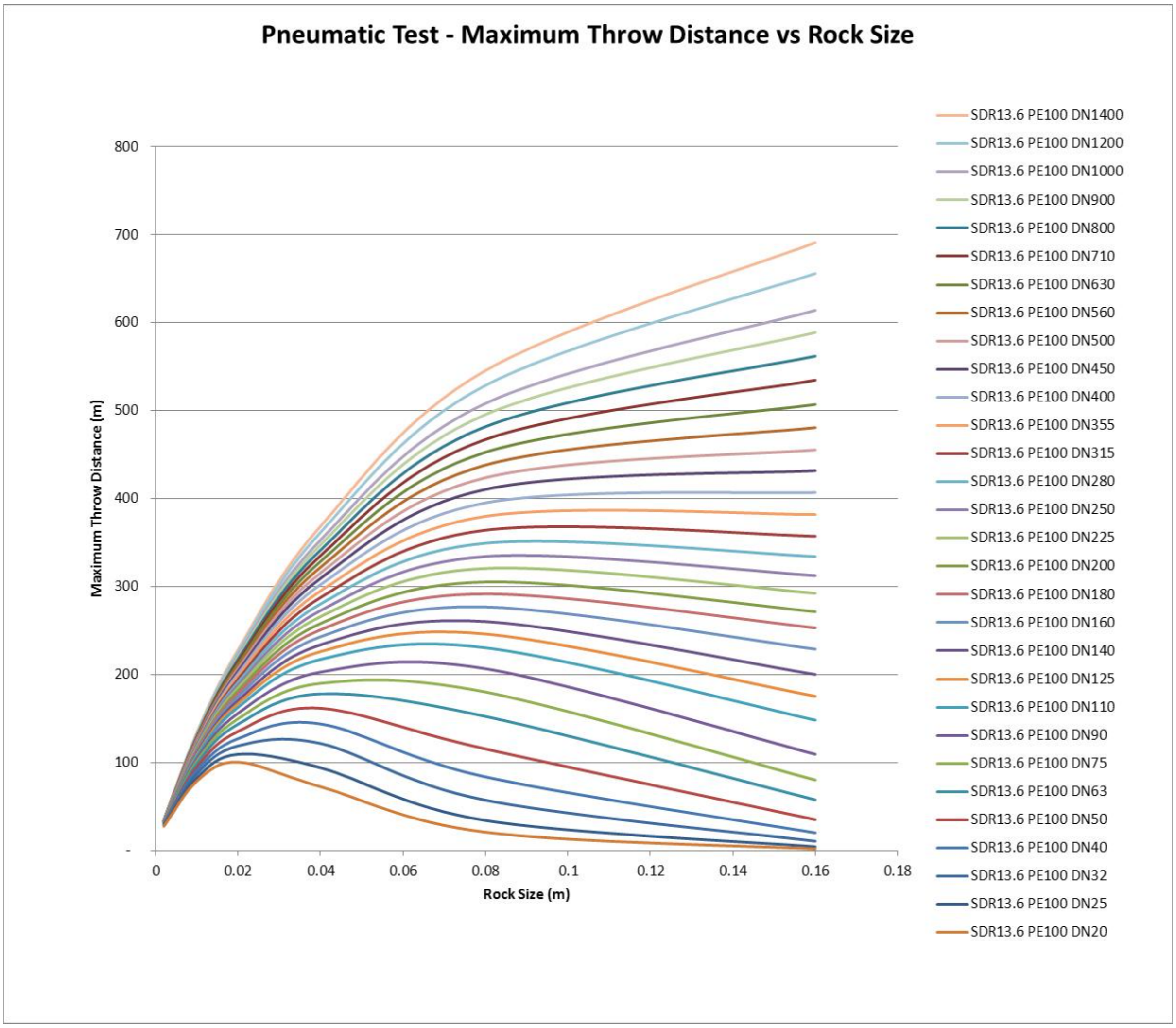
SDR 9 PE100. at Test Pressure of 2.5 MPa (full bore rupture).



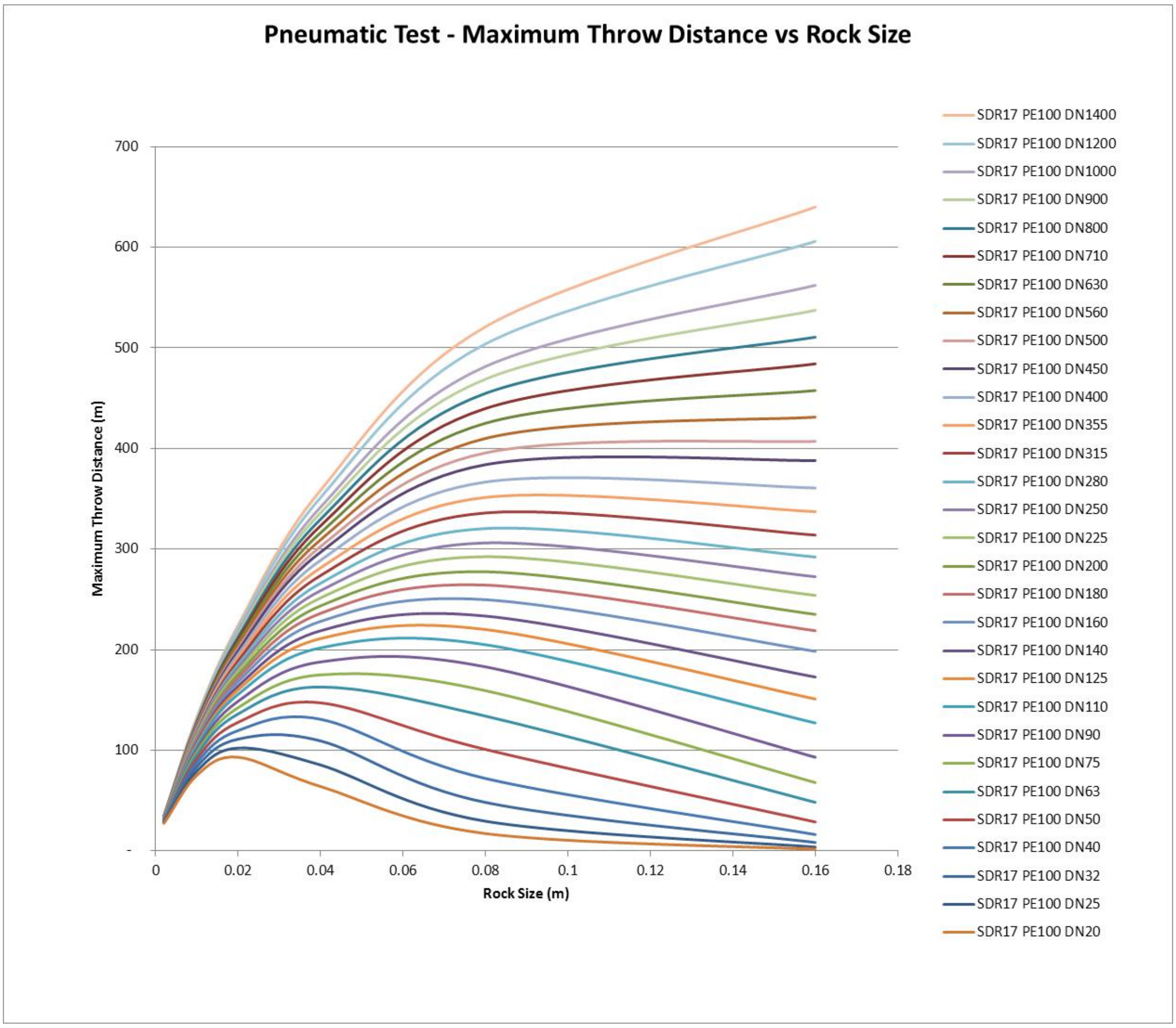
SDR 11 PE100 at Test Pressure of 2 MPa (full bore rupture).



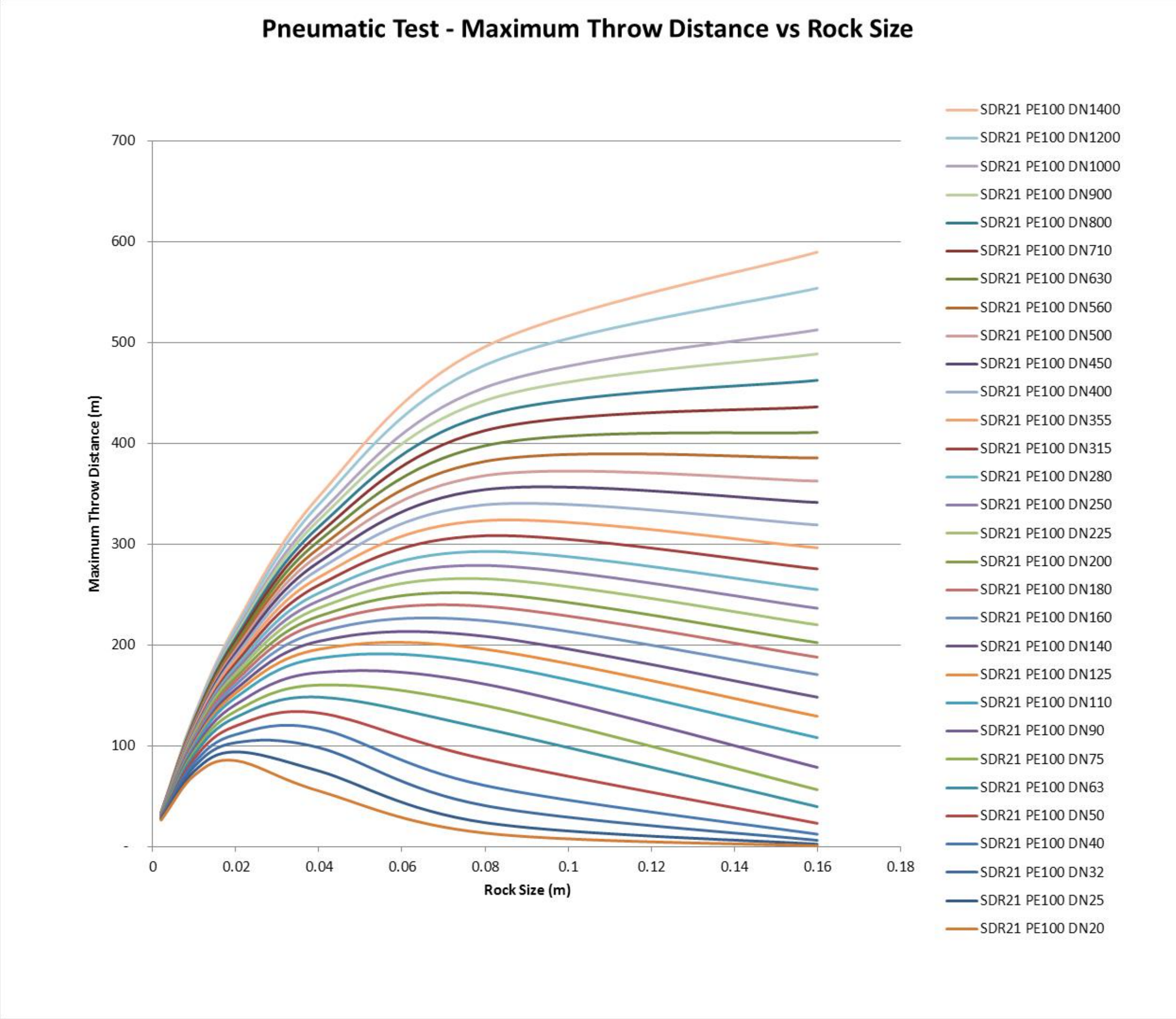
SDR 13.6 PE100 at Test Pressure of 1.588 MPa (full bore rupture).



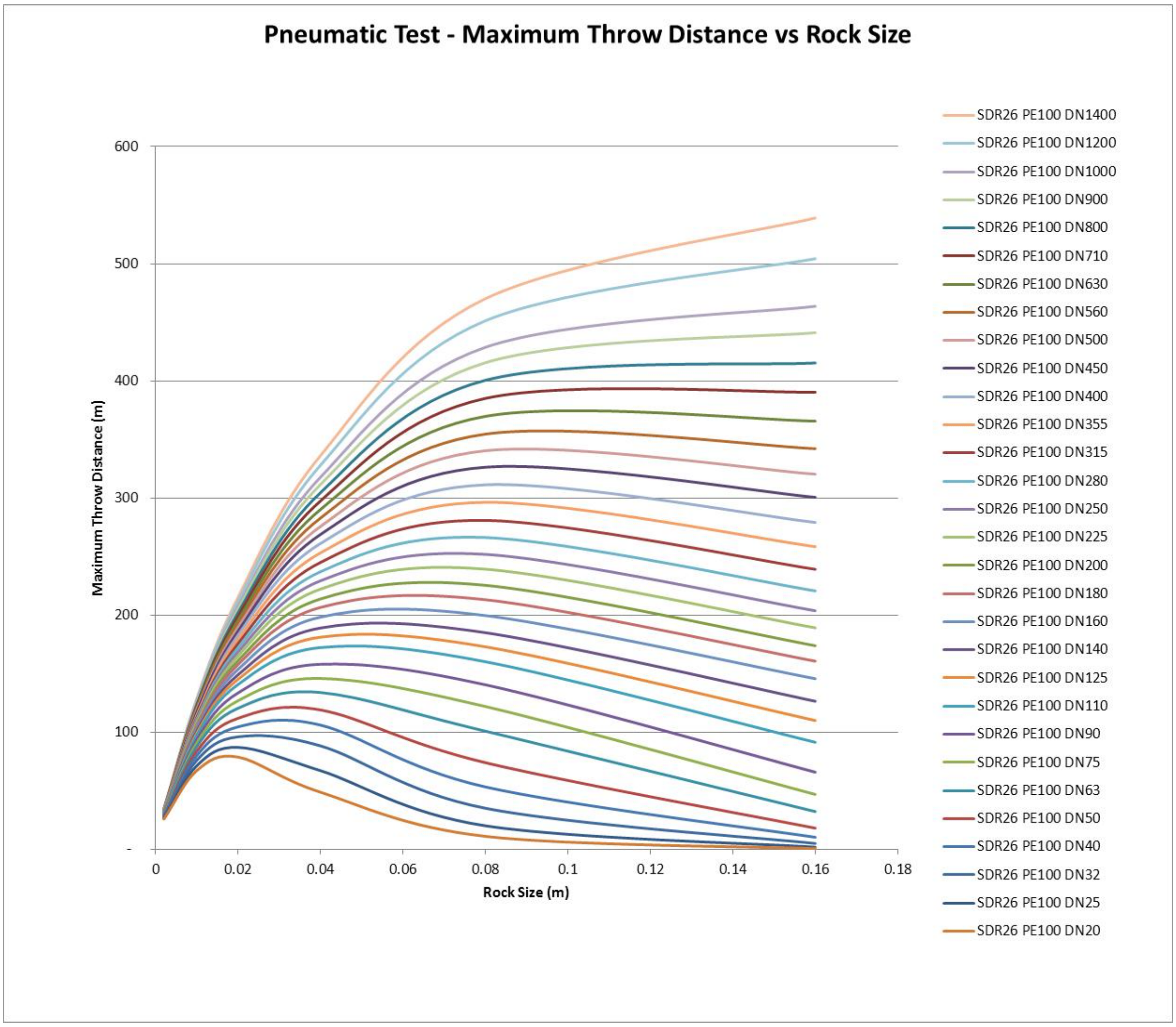
SDR 17 PE100 at Test Pressure of 1.25 MPa (full bore rupture).



SDR 21 PE100 at Test Pressure of 1 MPa (full bore rupture).



SDR 26 PE100 at Test Pressure of 800 kPa (full bore rupture).



SDR 33 PE100 at Test Pressure of 625 kPa (full bore rupture).