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British Precast
Drainage Association

Publications from the British Precast Drainage Association (BPDA):

BPDA was formed in 2017 from the integration of the Concrete Pipeline Systems Association (CPSA) and the Box Culvert Association (BCA).

Information published by both CPSA and BCA will be rebranded and replaced as BPDA in due course. New material will be branded BPDA.

All CPSA and BCA web traffic will be redirected to the new BPDA web site at www.precastdrainage.co.uk

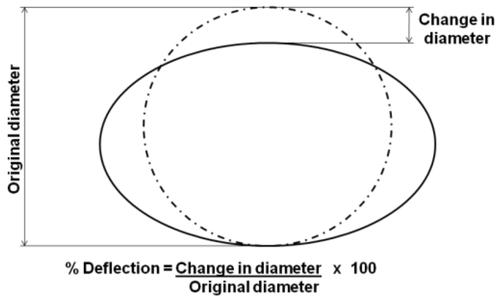
The impact of pipe deflection on structural integrity, hydraulic performance and suitability for adoption

Pipes such as plastic, grp and corrugated steel are commonly regarded as "flexible" if they have the ability to deflect 2% or more without cracking. A critical aspect of flexible pipe design is to minimise ring deflection to ensure good, long-term performance of the pipe.

Flexible Pipeline Systems

- Flexible pipes vary in stiffness from product to product. This means that the ability of different pipes to resist deflection will also vary.

- It is the pipe-soil interaction that is the major component of flexible pipe design. As the load on a flexible pipe increases, it becomes oval with the vertical diameter of the pipe decreasing and the horizontal diameter of the pipe increasing. This decrease in vertical diameter is termed the deflection, expressed as a percentage.



- Ring deflection is a critical component of flexible pipe performance and an important measure for assessing the quality of the installation. While most of the deflection of a flexible pipe normally occurs in the first few months after backfilling, it can continue to increase for several years, especially for plastic pipes under sustained loading or fluctuating groundwater levels.

- This is why it is important that the initial deflection test should be performed not sooner than 30 days after the completion of backfilling and installation of service connections.

- The shape of a flexible pipe can go through several changes before it reaches its final installation condition. For example, the initial shape of a thermoplastic pipe is rarely a perfect circle if left out in the hot sun, inadequately secured for transport over long distances or left in stock / on site for extensive periods prior to installation. Sometimes, the pipe's own weight can cause the pipe to sag if not supported with temporary internal struts to keep the pipe as round as possible during installation.

- A proper flexible pipe design should specify the allowable deflection for an explicit pipe product and stipulate the soil embedment necessary to ensure the pipe will not deflect more than this allowable limit. This is done by specifying a trench width that is appropriate for the native soil condition using the proper granular backfill materials, completely surrounding the pipe without gaps or foreign objects and with sufficient compaction effort over the entire cross-section and length of the pipeline.

- The allowable deflection limit is different for various flexible pipe materials. Applying a standard allowable deflection such as 6% will provide a factor of safety ranging from more than 4 to less than 1 (likely failure) depending on the stability and load-carrying capability of the soil around the pipe.

- The long-term performance history of many flexible pipe products is limited so it can be difficult to identify the highest quality flexible pipes available for the lifetime of a project.

Inspection and ring deflection testing

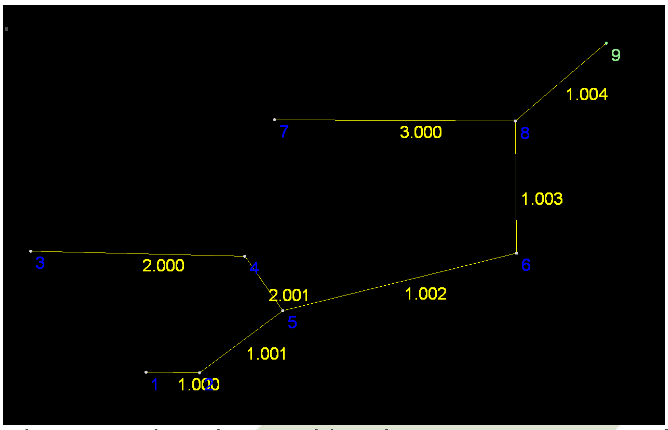
- Although useful for visually checking the condition of pipelines, most CCTV pipeline inspection techniques are not adequate for checking deflection. Pipe materials with black interiors make it difficult to perform even routine CCTV visual inspections and some authorities such as the Region of Peel in Ontario, Canada require only plastic pipe with light coloured interiors.
- A common technique for measuring pipeline deflection is using a laser profiler mounted to a CCTV camera. A beam in the form of a ring is projected onto the internal surface of the pipe and the recorded video image is then processed by computer software to produce a continuous 3D model of the pipeline. This information can be easily analysed for deflection issues and can help determine if a pipe is changing by comparing data recorded over time.

Inverse curvature outlined by laser profiler
(Image: Courtesy of Maverick Inspection Ltd.)

Hydraulic Performance

- The **internal diameter** of a flexible pipe may not be what the design engineer assumes. Discrepancies of more than 3% of the nominal pipe size are possible which can lead to errors in the anticipated hydraulic performance. For example, according to Hydraulics Research Design Tables based on Colebrook-White equation for pipes flowing full and using a hydraulic roughness Ks = 0.6mm for storm water sewers, a DN300 pipe laid at a gradient of 1:60 will have a reduction in capacity from 140 l/s to 136 l/s if the internal diameter is 291mm, i.e -3% of the nominal 300mm internal diameter.
- The **ovalisation** of flexible pipes (and other configurations in more extreme cases) will also reduce the hydraulic effciciency of pipelines. For example, in storm water sewers the majority of rainfall events will lead to fows within pipes at less than 50% proportional depth. An ovalised pipe will lead to lower velocities within the pipe at a specific flow rate than the original circular profile. This in turn may lead to greater risk of sedimentation and accumulation of detritus within the pipeline. This may be of particular relevance in areas where extended dry periods exist, high intensity rainfall at or close to the design value, where self-cleansing velocities are achieved, is encountered on an infrequent basis or where the sediment entering the system is significant.
- Most flexible sewer pipes incorporate a “ribbed” structure to the outer wall of the pipe to provide increased ring stiffness whilst keeping material content and weight to a minimum. Often, the inner surface of the pipe will follow the profile of the external ribs, resulting in a **corrugated** internal surface. The hydraulic roughness of a corrugated surface is significantly greater than a pipe with a smooth bore and can have a significant effect on the capacity of a pipeline system. Consequently, the hydraulic roughness of corrugated plastic pipes can be expected to be greater than the roughness of equivalent diameter smooth bore concrete pipes.
- It is also important that pipelines maintain their **longitudinal straightness** to ensure optimum hydraulic efficiency. It is essential that all pipes are laid with a proper understanding of the ground conditions and with sufficient support to the buried structure. Without appropriate support, pipes can deviate out of alignment and generate additional head loss within the system. Flexible pipes have low resistance to bending and can be particularly vulnerable to ground movement over their length.

Example: Effect of corrugation on hydraulic performance



Pipe network under consideration

Pipe type	Manning's Roughness Coefficients		
	High	Average	Low
Asbestos-Cement Pipe	0.011	0.013	0.015
Cast Iron (new)	0.012	0.0125	0.013
Clay Pipe	0.011	0.013	0.015
Concrete - steel forms		0.011	
Concrete - finished		0.012	
Concrete - Wooden forms		0.015	
Concrete - centrifugally spun		~~0.013~~	
Corrugated metal		0.022	
Galvanised Iron		0.016	
Plastic		~~0.009~~	
Polyethylene PE (corrugated inner walls)	0.018	0.0215	0.025
Polyvinyl Chloride (pvc)	0.009	0.01	0.011
Steel -smooth		0.012	

Manning's n values for different pipe surfaces

Hydraulic roughness

Control case
Ks = 0.6mm (Colebrook-White) as defined for storm water sewers in Sewers for Adoption 6th Edition

Corugated pipe case
n = 0.022 (Manning) as defined in reference literature

Control case

STORM SEWER DESIGN by the Modified Rational Method

Design Criteria for Control

Pipe Sizes STANDARD Manhole Sizes STANDARD

FSR Rainfall Model - England and Wales

Return Period (years)	1	Add Flow / Climate Change (%)	0
M5-60 (mm)	20.000	Minimum Backdrop Height (m)	0.200
Ratio R	0.400	Maximum Backdrop Height (m)	0.000
Maximum Rainfall (mm/hr)	0	Min Design Depth for Optimisation (m)	1.200
Foul Sewage (l/s/ha)	0.00	Min Vel for Auto Design only (m/s)	0.75
Volumetric Runoff Coeff.	0.750	Min Slope for Optimisation (1:X)	500

Designed with Level Soffits

Network Design Table for Control

PN	Length (m)	Fall (m)	Slope (1:X)	Area (ha)	T.E. (mins)	DWF (l/s)	k (mm)	HYD SECT	DIA (mm)
1.000	20.000	1.200	16.7	0.200	5.00	0.0	0.600	o	225
1.001	39.000	0.488	79.9	0.120	0.00	0.0	0.600	o	300
2.000	80.000	0.360	222.2	0.200	5.00	0.0	0.600	o	600
2.001	25.000	0.888	28.2	0.120	0.00	0.0	0.600	o	225
1.002	90.000	0.360	250.0	0.115	0.00	0.0	0.600	o	375
1.003	50.000	0.350	142.9	0.350	0.00	0.0	0.600	o	375
3.000	90.000	0.480	187.5	0.000	5.00	0.0	0.600	o	750
1.004	45.000	0.300	150.0	0.070	0.00	0.0	0.600	o	375

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ Area (ha)	Σ DWF (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
1.000	0.00	5.10	100.500	0.200	0.0	0.0	0.0	3.22	128.1	0.0
1.001	0.00	5.47	99.225	0.320	0.0	0.0	0.0	1.76	124.4	0.0
2.000	0.00	5.82	100.060	0.200	0.0	0.0	0.0	1.63	460.7	0.0
2.001	0.00	5.99	99.700	0.320	0.0	0.0	0.0	2.48	98.4	0.0
1.002	0.00	7.30	98.662	0.755	0.0	0.0	0.0	1.14	126.1	0.0
1.003	0.00	7.85	98.302	1.105	0.0	0.0	0.0	1.51	167.2	0.0
3.000	0.00	5.74	97.950	0.000	0.0	0.0	0.0	2.04	901.4	0.0
1.004	0.00	8.36	97.470	1.175	0.0	0.0	0.0	1.48	163.1	0.0

Corrugated pipe case

STORM SEWER DESIGN by the Modified Rational Method

Design Criteria for Polyvinylene (PE) corrogated inner walls

Pipe Sizes STANDARD Manhole Sizes STANDARD

FSR Rainfall Model - England and Wales

Return Period (years)	1	Add Flow / Climate Change (%)	0
M5-60 (mm)	20.000	Minimum Backdrop Height (m)	0.200
Ratio R	0.400	Maximum Backdrop Height (m)	0.000
Maximum Rainfall (mm/hr)	0	Min Design Depth for Optimisation (m)	1.200
Foul Sewage (l/s/ha)	0.00	Min Vel for Auto Design only (m/s)	0.75
Volumetric Runoff Coeff.	0.750	Min Slope for Optimisation (1:X)	500

Designed with Level Soffits

Network Design Table for Polyvinlyene (PE) corrogated inner walls

PN	Length (m)	Fall (m)	Slope (1:X)	Area (ha)	T.E. (mins)	DWF (l/s)	n	HYD SECT	DIA (mm)
1.000	20.000	1.200	16.7	0.200	5.00	0.0	0.022	o	225
1.001	39.000	0.488	79.9	0.120	0.00	0.0	0.022	o	300
2.000	80.000	0.360	222.2	0.200	5.00	0.0	0.022	o	600
2.001	25.000	0.888	28.2	0.120	0.00	0.0	0.022	o	225
1.002	90.000	0.360	250.0	0.115	0.00	0.0	0.022	o	375
1.003	50.000	0.350	142.9	0.350	0.00	0.0	0.022	o	375
3.000	90.000	0.480	187.5	0.000	5.00	0.0	0.022	o	750
1.004	45.000	0.300	150.0	0.070	0.00	0.0	0.022	o	375

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ Area (ha)	Σ DWF (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
1.000	0.00	5.20	100.500	0.200	0.0	0.0	0.0	1.63	65.0	0.0
1.001	0.00	5.92	99.225	0.320	0.0	0.0	0.0	0.90	63.9	0.0
2.000	0.00	6.55	100.060	0.200	0.0	0.0	0.0	0.86	243.4	0.0
2.001	0.00	6.88	99.700	0.320	0.0	0.0	0.0	1.26	50.0	0.0
1.002	0.00	9.41	98.662	0.755	0.0	0.0	0.0	0.59	65.5	0.0
1.003	0.00	10.47	98.302	1.105	0.0	0.0	0.0	0.78	86.7	0.0
3.000	0.00	6.38	97.950	0.000	0.0	0.0	0.0	1.09	480.4	0.0
1.004	0.00	11.45	97.470	1.175	0.0	0.0	0.0	0.77	84.6	0.0

In this simple pipeline network example, pipe sizes and gradients are optimised for the control case and kept the same for the corrugated pipe case. We can see that the theoretical capacity of the system is reduced as a result of the increased hydraulic resistance created by the internal pipe corrugations.

1 year Return Period Summary of Critical Results by Maximum Level (Rank 1) for Control

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440, 2160, 2880, 4320, 5760, 7200, 8640, 10080
Return Period(s) (years) 1, 30, 100
Climate Change (%) 0, 0, 0

PN	Storm	Return Period	Climate Change	First X Surcharge	First Y Flood	First Z Overflow	O/F Act.	Lvl Exc.
1.000	15 Winter	1	0%	100/15 Summer				
1.001	15 Winter	1	0%	30/15 Summer				
2.000	15 Winter	1	0%	100/15 Winter				
2.001	15 Winter	1	0%	30/15 Summer				
1.002	15 Winter	1	0%	30/15 Summer				
1.003	15 Winter	1	0%	30/15 Summer				
3.000	360 Winter	1	0%					
1.004	15 Winter	1	0%	30/15 Summer				

PN	US/MH Name	Water Level (m)	Surch'ed Depth (m)	Flooded Volume (m³)	Flow / Cap.	O'flow (l/s)	Pipe Flow (l/s)	Status
1.000	1	100.575	-0.150	0.000	0.24	0.0	27.8	OK
1.001	2	99.351	-0.174	0.000	0.36	0.0	41.6	OK
2.000	3	100.161	-0.499	0.000	0.06	0.0	26.9	OK
2.001	4	99.805	-0.120	0.000	0.45	0.0	40.7	OK
1.002	5	98.914	-0.123	0.000	0.74	0.0	89.4	OK
1.003	6	98.559	-0.118	0.000	0.81	0.0	124.7	OK
3.000	7	97.950	-0.750	0.000	0.00	0.0	0.0	OK
1.004	8	97.740	-0.105	0.000	0.86	0.0	128.6	OK

1 year Return Period Summary of Critical Results by Maximum Level (Rank 1) for Polyvinylene (PE) corrogated inner walls

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440, 2160, 2880, 4320, 5760, 7200, 8640, 10080
Return Period(s) (years) 1, 30, 100
Climate Change (%) 0, 0, 0

PN	Storm	Return Period	Climate Change	First X Surcharge	First Y Flood	First Z Overflow	O/F Act.	Lvl Exc.
1.000	15 Winter	1	0%	30/15 Summer	100/15 Summer			4
1.001	15 Winter	1	0%	30/15 Summer	30/15 Summer			8
2.000	15 Winter	1	0%	30/15 Summer				
2.001	15 Winter	1	0%	30/15 Summer	100/15 Winter			3
1.002	15 Winter	1	0%	1/15 Summer	30/15 Winter			7
1.003	15 Winter	1	0%	1/15 Summer	100/15 Summer			4
3.000	360 Winter	1	0%					
1.004	15 Winter	1	0%	1/15 Winter				

PN	US/MH Name	Water Level (m)	Surch'ed Depth (m)	Flooded Volume (m³)	Flow / Cap.	O'flow (l/s)	Pipe Flow (l/s)	Status
1.000	1	100.605	-0.120	0.000	0.44	0.0	27.7	OK
1.001	2	99.407	-0.118	0.000	0.66	0.0	41.2	OK
2.000	3	100.197	-0.463	0.000	0.11	0.0	24.9	OK
2.001	4	99.850	-0.075	0.000	0.77	0.0	37.9	OK
1.002	5	99.251	0.214	0.000	1.17	0.0	75.8	SURCHARGED
1.003	6	98.732	0.055	0.000	1.09	0.0	92.8	SURCHARGED
3.000	7	97.950	-0.750	0.000	0.00	0.0	0.0	OK
1.004	8	97.861	0.016	0.000	1.05	0.0	86.9	SURCHARGED

In the 1 year return period design case, we can see that surcharging occurs in some of the lengths of corrugated pipeline. No surcharging occurs in the control case, as required.

30 year Return Period Summary of Critical Results by Maximum Level (Rank 1) for Control

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440, 2160, 2880, 4320, 5760, 7200, 8640, 10080
Return Period(s) (years) 1, 30, 100
Climate Change (%) 0, 0, 0

PN	Storm	Return Period	Climate Change	First X Surcharge	First Y Flood	First Z Overflow	O/F Act.	Lvl Exc.
1.000	15 Winter	30	0%	100/15 Summer				
1.001	15 Winter	30	0%	30/15 Summer				
2.000	15 Winter	30	0%	100/15 Winter				
2.001	15 Winter	30	0%	30/15 Summer				
1.002	15 Winter	30	0%	30/15 Summer				
1.003	15 Winter	30	0%	30/15 Summer				
3.000	15 Winter	30	0%					
1.004	15 Winter	30	0%	30/15 Summer				

PN	US/MH Name	Water Level (m)	Surch'ed Depth (m)	Flooded Volume (m³)	Flow / Cap.	O'flow (l/s)	Pipe Flow (l/s)	Status
1.000	1	100.672	-0.053	0.000	0.59	0.0	68.2	OK
1.001	2	100.338	0.813	0.000	0.83	0.0	95.8	SURCHARGED
2.000	3	100.251	-0.409	0.000	0.16	0.0	65.5	OK
2.001	4	100.217	0.292	0.000	0.96	0.0	86.8	SURCHARGED
1.002	5	100.003	0.966	0.000	1.38	0.0	166.0	SURCHARGED
1.003	6	99.328	0.651	0.000	1.67	0.0	258.8	SURCHARGED
3.000	7	98.138	-0.562	0.000	0.00	0.0	2.0	OK
1.004	8	98.138	0.293	0.000	1.43	0.0	213.5	SURCHARGED

30 year Return Period Summary of Critical Results by Maximum Level (Rank 1) for Polyvinylene (PE) corrogated inner walls

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440, 2160, 2880, 4320, 5760, 7200, 8640, 10080
Return Period(s) (years) 1, 30, 100
Climate Change (%) 0, 0, 0

PN	Storm	Return Period	Climate Change	First X Surcharge	First Y Flood	First Z Overflow	O/F Act.	Lvl Exc.
1.000	15 Winter	30	0%	30/15 Summer	100/15 Summer			4
1.001	15 Winter	30	0%	30/15 Summer	30/15 Summer			8
2.000	15 Winter	30	0%	30/15 Summer				
2.001	15 Winter	30	0%	30/15 Summer	100/15 Winter			3
1.002	15 Winter	30	0%	1/15 Summer	30/15 Winter			7
1.003	15 Winter	30	0%	1/15 Summer	100/15 Summer			4
3.000	30 Winter	30	0%					
1.004	30 Winter	30	0%	1/15 Winter				

PN	US/MH Name	Water Level (m)	Surch'ed Depth (m)	Flooded Volume (m³)	Flow / Cap.	O'flow (l/s)	Pipe Flow (l/s)	Status
1.000	1	101.806	1.081	0.000	0.80	0.0	50.4	FLOOD RISK
1.001	2	101.002	1.477	2.318	1.06	0.0	66.6	FLOOD
2.000	3	101.170	0.510	0.000	0.25	0.0	58.5	SURCHARGED
2.001	4	101.154	1.229	0.000	1.09	0.0	53.4	SURCHARGED
1.002	5	100.600	1.563	0.027	1.73	0.0	111.8	FLOOD
1.003	6	99.937	1.260	0.000	2.12	0.0	179.5	FLOOD RISK
3.000	7	98.308	-0.392	0.000	0.00	0.0	1.6	OK
1.004	8	98.308	0.463	0.000	1.61	0.0	133.1	SURCHARGED

In the 30 year return period design case, the corrugated pipeline is incapable of operating within its discharge capacity and several lengths in the network are liable to flooding. Surcharging only is generally permissible at the 30 year design event.

If the corrugated pipe network was optimised to meet self-cleansing velocities, it is possible that the slope of the pipeline would need to be increased to a point where the downstream end of the network is at a significantly lower level. If the network is connecting into an existing system at a predetermined level, the increased slopes / lower downstream inverts could cause a problem. This may be compensated, at least in part, by increasing pipe sizes and using reduced falls although self-cleansing velocities may be more difficult to achieve.

In either case, increased pipe sizes or increased installation depth due to greater falls will lead to higher installed costs.

Implications on sewer adoption

- Wastewater sewers need to be inspected to ensure they have been built to an acceptable standard prior to being accepted for adoption by a water company.
- The transfer of private sewers to the ownership of the water companies in England and Wales will coincide with the introduction of a Mandatory New Build Standard for Sewers and the requirement that 100% of new sewer pipelines constructed and connected to the foul sewerage network must be submitted to the relevant water company for adoption.
- This puts greater pressure on the contractor to ensure that Best Practice is maintained throughout the installation of the pipeline and highlights the importance of avoiding short-cuts to save time and money. The cost of fixing mistakes to ensure adoption requirements are met will normally far outweigh the cost of getting it right first time.
- This means that designers, installers and operators need to think carefully about the type of sewerage pipeline material used in a project and the different levels of risk associated with failure to meet adoption requirements.
- Rigid pipeline materials such as concrete are structural elements and the integrity of a buried concrete pipeline is derived mainly from the pipe itself. In contrast, the structural performance of flexible pipes are almost entirely dependent on the quality of workmanship on site and as such, may represent a greater risk in terms of excessive deflection and meeting other adoption standards.

For further information please contact your usual supplier:

Buchan Concrete Solutions
Tel: 01606 843 500
Web: www.buchanconcrete.com

CPM Group
Tel: 0117 981 2791
Web: www.cpm-group.com

F P McCann
Tel: 01530 240 000
Web: www.fpmccann.co.uk

Milton Precast
01795 425191
www.miltonprecast.com

Stanton Bonna
Tel: 0115 944 1448
Web: www.stanton-bonna.co.uk

Concrete Pipeline Systems Association - 60 Charles Street, Leicester, LE1 1FB.
Tel: 0116 253 6161 ¦ Fax: 0116 251 4568 ¦ Email: mail@concretepipes.co.uk ¦ Web: www.concretepipes.co.uk