Monitoring Urban Drainage: plug & pray

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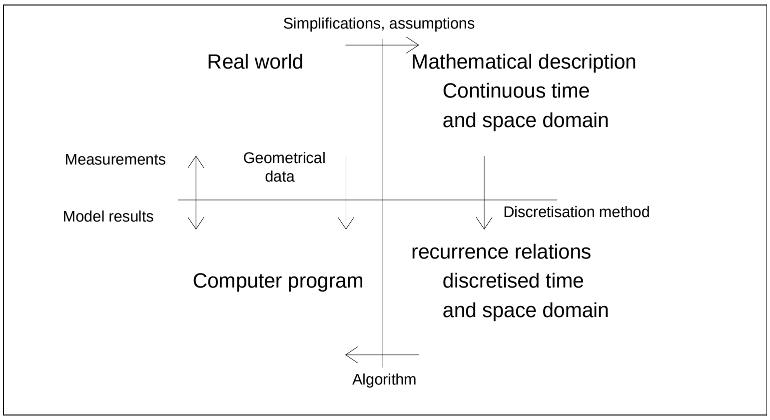
Why monitor urban drainage systems?



Why monitor urban drainage systems?

- Actual performance vs design performance (mainly hydraulics)
- Real Time Control (hydraulics+water quality)
- Impact on environment (receiving surface water bodies, hydraulics +water quality)
- Actual safety level against collapse (inspection techniques)
- Actual safety level against flooding/health risks (inspection techniques + hydraulics + quality)

Some practical issues (e.g. raingauges)

What would we like to achieve?

- What is the actual constructive strength and stability of a conduit?
- What is the hydraulic capacity of a conduit?
- What is the protection level against flooding in a catchment?
- What is the actual health risk in a catchment due to flooding?

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Most commonly applied technique CCTV

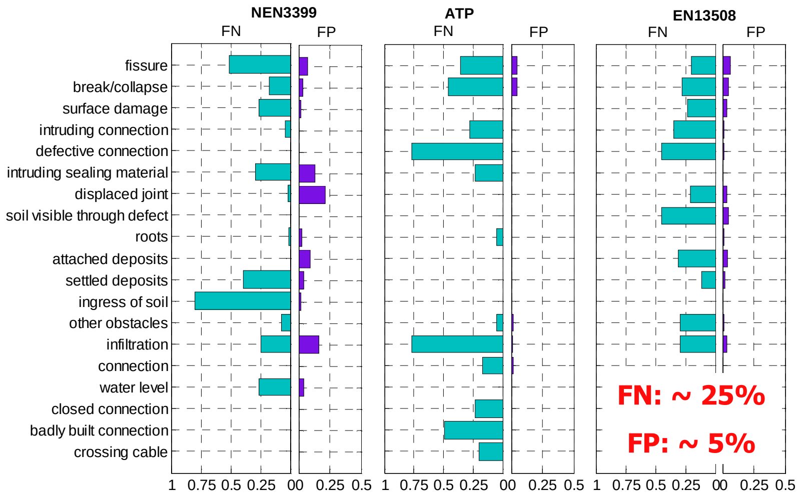
CCTV system

evaluating inspection results

Does CCTV provide us with the data we need?

- Not really:
  - No quantitative information on hydraulic capacity
  - No quantitative information on constructive strength & stability.
  - Further: serious doubts on the reliability of the data obtained!!!!!!!!

Consistency of CCTV data (Dirksen et al(2013))

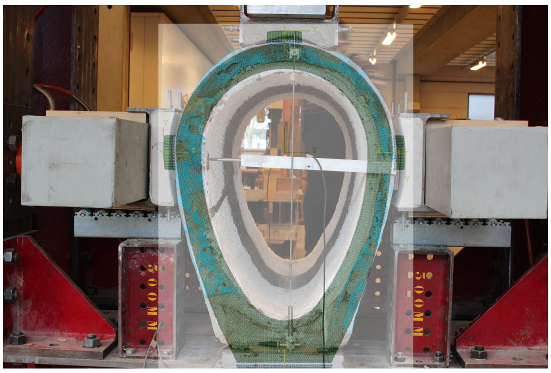


Range of techniques has been developed

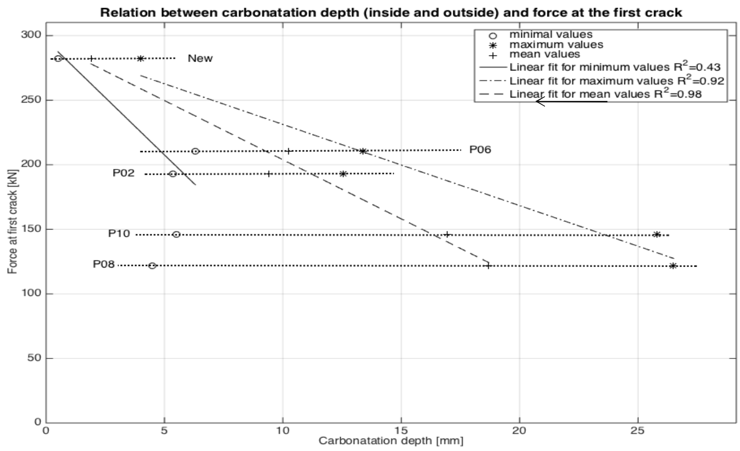
- Laser profiling
- Core sample analysis
- Infiltration by means of DTS
- Eliminate human factor in interpretation of images (deep learning methods)
- Ground penetrating radar
- Acoustic evaluation
- IR cameras
- Sonar
- UV light
- Electro tomography
- Deformation/stress monitoring

Core sample analysis

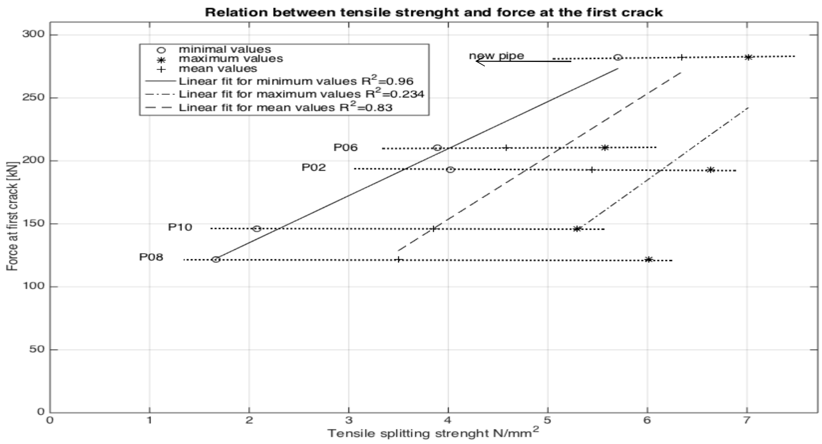
- 5 pipes (new, 60 and 90 years in 'service') tested on:
  - Carbonatation depth
  - Tensile splitting strenght
  - Flexing strenght
  - Pressure strenght
  - Density
  - Porosity
  - Failing strenght



Carbonatation depth



Tensile splitting strenght



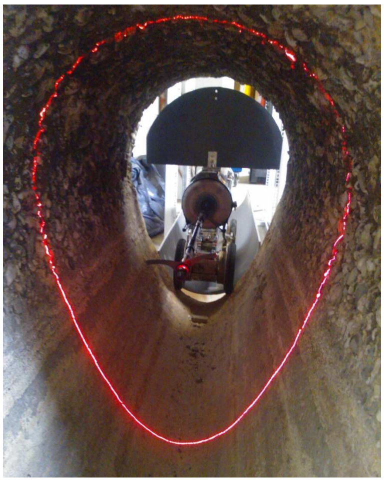
How many samples per m' to obtain a statistical significant value?

Pipe	Parameter	Initial estimate for the mean value	Initial estimate for the standard deviation	Sample size for the mean values. Based on Eq. (1)
New	Remaining healthy material	67.3 mm	2.05 mm	1
	Density	2317 kg/m^2	11.5 kg/m^3	1
	Tensile splitting strength	6.34	0.86	7
P02	Remaining healthy material	64.0 mm	5.4 mm	3
	Density	2339 kg/m^3	2846 kg/m^3	1
	Tensile splitting strength	5.444 N/mm^2	0.899 N/mm^2	11
P06	Remaining healthy material	61 mm	3.4 mm	2
	Density	2318 kg/m^3	30.478 kg/m^3	1
	Tensile splitting strength	4.583 N/mm^2	0.527 N/mm^2	6
P08	Remaining healthy material	40.3 mm	8.9 mm	19
	Density	2316 kg/m^3	43,25 kg/m^2	1
	Tensile splitting strength	3.499 N/mm^2	1.322 N/mm^2	55
P10	Remaining healthy material	44.3 mm	11.0 mm	24
	Density	2322 kg/m^3	41.042	1
	Tensile splitting strength	3.85 N/mm^2	2.08 N/mm^2	112

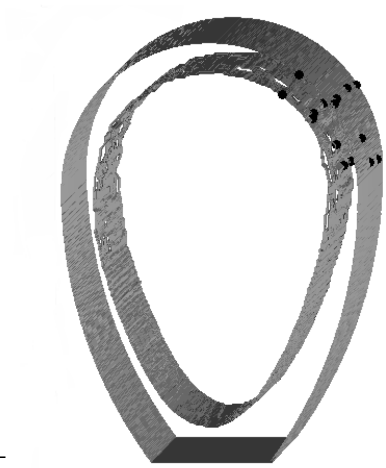
Conclusions

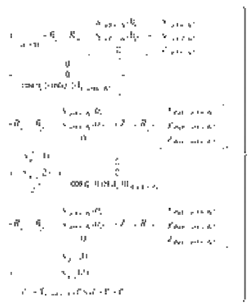
- You can obtain materials characteristics by means of core sample analysis
- However:
  - The number of samples per m' to be taken will influence the functionality of the pipe strongly (you know exactly how strong the pipe was before the investigation)
  - No information on the geometry
  - Using just one sample for a stretch of pipes, as is usually done, is really "plug and pray", since the outcome of any calculation is just one realization in a Monte Carlo simulation.

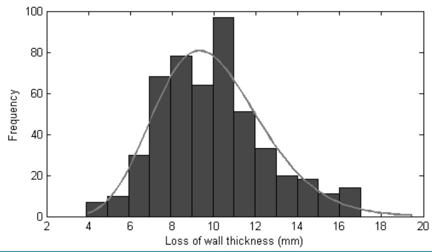
Laser profiling/scanning



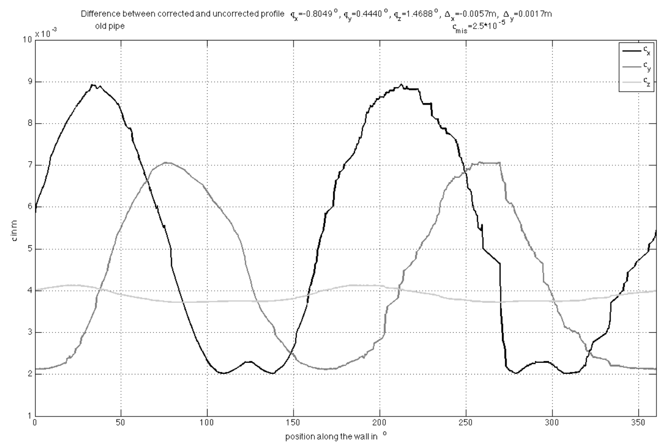
3D information (1 Tb/m !!!!, see clemens et al (2015), Lepot et al (2017) and Stanic et al (2017)



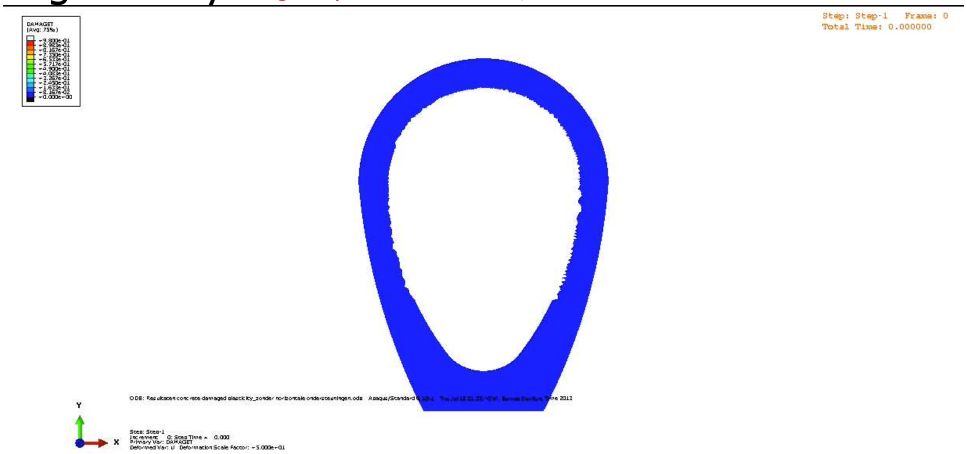




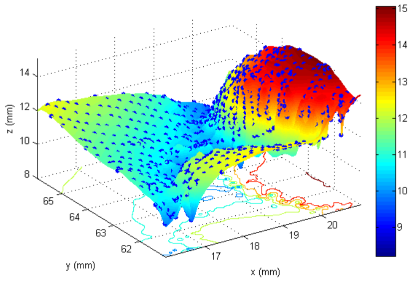
With known confidence level



FEM analysis based on measured geometry. Plug&Pray: what about loads, soil characteristics?



In situ determination hydraulic roughness



Reiability

Resistence factor (Ali and Uijttewaal, 2012)	Determined by laser scanning
0.0666	0.0687
0.0626	0.0654
0.0626	0.0604
0.0698	0.0670

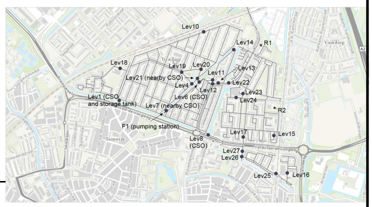
Actual hydraulic roughnesses. Plug & Pray: what about local losses?

Sample	k_s (mm)	σ_{tot} (mm)
Validation	5.33	1.06
New pipe	0.54	0.07
Breda 1st pipe		
invert	0.53	0.13
lateral	1.48	0.05
crown	0.95	0.05
Breda 2nd pipe		
invert	0.54	0.03
lateral	0.94	0.04
crown	1.1	0.03
The Hague 1st pipe		
invert	0.89	0.11
lateral	1.5	0.05
crown	9.93	0.32
The Hague 2nd pipe		
invert	0.76	0.09
lateral	1.44	0.06
crown	12.74	1.62

	h_f (m)				
Dimension (mm)	New pipe	Breda 1st pipe	Breda 2nd pipe	The Hague 1st pipe	The Hague 2nd pipe
300/450	0.200	0.232	0.221	0.335	0.363
400/600	0.136	0.158	0.151	0.228	0.247
500/750	0.101	0.118	0.112	0.170	0.184
700/1050	0.065	0.075	0.071	0.108	0.117
1000/1500	0.040	0.047	0.044	0.067	0.073
1200/1800	0.031	0.037	0.035	0.053	0.057
1600/2400	0.021	0.025	0.024	0.036	0.039

Monitoring increase in health risk due to a lack of maintenance (van Bijnen et al (2016 and (2017))

- Project starts in 2008
- First inspection of the whole catchment: root intrusion on a moderate massive scale
- Install a lot of water level sensors, 3 rain gauges, discharge measuirng device in the pumping station
- During the project the maintenance department removed radio transmitters from the site (I guess we plugged but forgot to pray…….).
- After 4 years the systems was cleaned out and we continued monitoring
- For both situations a full detailed hydraulic model was calibrated
- Based on time series taking into account all uncertainties for each manhole a frequency and duration estimate for flooding was made.
- Based on a model by de Man et al (2014) the health risk was determined.



Summary statistics of probability of infection per year for adults in the 'Tuindorp' catchment

Flooded area	Reference* (clean system)	Root introsion and sediemnts present	Shift*	95-perc.
50 m^2	5.3e-3	8.1e-3	2.8e-3	1.4e-3
75 m^2	5.0e-3	7.6e-3	2.7e-3	1.5e-3
100 m^2	4.7e-3	7.2e-3	2.5e-3	1.5e-3

Conclusions health risk

- With a lot of assumptions a link has been made between maintenance of a sewer system and health risk was made.
- Plug&Pray: Human behaviour? Not taken into account, over-all validation: extremely difficult.

References (1)

Marco van Bijnen, Jeroen Langeveld, Hans Korving, François Clemens (2017[a]) Calibration of hydrodynamic models driving sewer maintenance. Structure and Infrastructure Engineering 13 (9), 1167-1185

Marco van Bijnen, Hans Korving, Jeroen Langeveld, François Clemens (2017[b]), subm Water Research) Quantitative assessment of impacts of sewer condition on health risk

De Man, H., Van den Berg, H.H.J.L., Leenen, E.J.T.M., Schijven, J.F., Schets, F.M., Van der Vliet, J.C. Van Knapen, F. De Roda Husman, A.M. (2014). Quantitative assessment of infection risk from exposure to waterborne pathogens in urban floodwater. Water Research, 48, 90-99.

F Clemens, N Stanić, W Van der Schoot, J Langeveld, M Lepot (2015) Uncertainties associated with laser profiling of concrete sewer pipes for the quantification of the interior geometry. Structure and Infrastructure Engineering 11 (9), 1218-1239

N Stanić, FHLR Clemens, JG Langeveld (2016) Estimation of Hydraulic Roughness of Concrete Sewer Pipes by Laser Scanning. Journal of Hydraulic Engineering 143 (2).

References (2)

N Stanić, M Lepot, M Catieau, J Langeveld, FHLR Clemens (2017) A technology for sewer pipe inspection (part 1): Design, calibration, corrections and potential application of a laser profiler Automation in Construction 75, 91-107

M Lepot, N Stanić, FHLR Clemens (2017) A technology for sewer pipe inspection (Part 2): Experimental assessment of a new laser profiler for sewer defect detection and quantification Automation in Construction 73, 1-11

J Dirksen, F Clemens, H Korving, F Cherqui, P Le Gauffre, T Ertl, H Plihal, Snaterse, C. (2013)_The consistency of visual sewer inspection data. Structure and Infrastructure Engineering 9 (3), 214-228