9th International Conference on Urban Drainage Modelling
Belgrade 2012

Comparison of core sampling and visual inspection for assessment of sewer pipe condition

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ABSTRACT

Sewer systems are costly to construct and even more costly to replace, requiring proper asset management Sewer asset management relies to a large extent on available information. In sewer systems where pipe corrosion is the dominant failure mechanism, visual inspection (CCTV) and core sampling are amongst the methods applied mostly to assess sewer pipe condition. This paper compares visual inspection and drill core analysis in order to enhance further understanding of the limitations and potentials of both methods. Both methods have been applied on a selected sewer reach in the city of the Hague, which was reportedly subject to pipe corrosion. Results show that both methods, visual inspection and core sampling, are associated with large uncertainties and that there is no obvious correlation between results of visual inspection and results of drill core analysis.

KEYWORDS

Asset management, CCTV, core sampling, inspection, sewer condition

1 INTRODUCTION

Sewer systems are capital intensive infrastructure systems, that have to last for decades. However, with time drainage systems deteriorate due to aging, overloading, misuse and mismanagement (Butler and Davies 2004). As many sewer systems have been constructed between 1950s and 1970s, the societal costs of managing the sewerage systems increased strongly over the past years. For instance, (Oosterom and Hermans 2005) report shows that the replacement value of the sewerage system in the Netherlands is around € 58 billion. Report also estimates that today's average annual sewerage tax per household in the Netherlands is € 125, which covers 87% of costs. Consequently, maintaining physical integrity and serviceability of the asset has become priority. Insight in the actual status of the assets is a prerequisite for adequate sewer asset management.

Many municipalities in the Netherlands determine sewer conditions by visual inspection, but only a few municipalities (depending on their needs and decisions), are combining that information with drill core analysis. For instance, the Sewerage Department of the Municipality of the Hague is determining the condition of the sewer system using visual inspection - closed circuit television (CCTV) and on drill core analysis. This is done to ensure that as little as possible sewer is replaced before the end of their service life, as well as to reduce the risk of sewer collapse before the scheduled replacement moment.

The city of the Hague has a relatively old sewer comparing to the rest of cities in the Netherlands. Approximately 37% of the existing sewer system was built before 1950 and it still functioning (Gemeente Den Haag 2011). The sewer system in the Hague is mainly combined system. The greatest part of the sewer consists of concrete (95%, this is approximately 2.4% renovated) and plastic (3.4%). In recent year sewer consists of (around 1.6%) materials such as glass-fibber reinforced plastic (GRP), masonry, cast iron, stoneware, steel and asbestos cement (Chan 2011). The old part of the city of Hague is located on old and young dunes area. This whole area is subjected to relatively low settling, whereas the newer parts of the Hague are built in areas where soil settles at a rate limiting the service life of the sewers. In the older parts of the city, sewer corrosion is the main failure mechanism leading to sewer rehabilitation. The sewers in this part of the city are typically replaced when they are about 70 to 100 years old. This is considerably later than in many other municipalities in the Netherlands (Gemeente Den Haag 2011).

The municipality of The Hague has about 1400 km of sewer pipe line and with a replacement value of approximately 2 billion euros requires, also from the legal duty, a rational and planned care. The moment of replacement is determined by age, hydraulic improvements and activities in the public spaces, such as road maintenance and redesign. The quality of the sewer largely determines the replacement strategy of the sewer. Therefore, knowledge on the sewer condition is necessary. This can be achieved only by conducting inspections and proper recording of them (Chan 2011). Deterioration of sewer pipes is one of the most important criteria for determining if replacement of the sewer is required due to the fact that there is little settlement occurring in the city area (Gemeente Den Haag 2011). Particularly decisions for replacement are made based on "surface damage" BAF (Nederlands Normalisatie-instituut 2004).

Recent research (Baur and Herz 2002; Dirksen et al. 2011) has shown that inspections are inherently unreliable, apart from the fact that visual inspection will not reveal invisible deterioration, like corrosion on the outside wall of a sewer. (Polder 1987) described deterioration processes of sewer pipes especially from a chemical and materials point of view, but did not give practical advice on how to deal with inspection and did not address the relationship between visual inspection and the quality of the concrete. On the other hand, (Stein 2001) tried to describe this relationship and has indicated that the manner of adjusting the cleaning nozzle can have strong impact on the concrete pipe. Based on the already mentioned situation in todays' practice it can be seen that decision on financial and social risks are linked mostly to visual inspection. Destructive methods like core sampling can provide additional valuable information about the strength properties of the sewer (De Silva et al. 2002). The potential gains of combining drill core analysis and video inspection should be assessed. To the author's knowledge no attempt to combine these two methods was reported so far.

The paper compares the results of the assessment of sewer corrosion based on CCTV inspection and core sampling, taking the uncertainty of both methods into account.

2 METHODOLOGY

The study was conducted in a sewer that according the municipal sewer rehabilitation plans was possibly to be replaced within a few years. The street is located in domestic housing area around dunes. In this area the groundwater is below the sewer invert level (Gemeente Den Haag 2011). The sewer system in the area is a combined sewer, egg-shaped with dimensions of 300/450 mm and made of concrete. Part of the sewer (about 274 m) was constructed in 1931 and the other part (about 42 m) was constructed in 1960.

On the selected location based on visual inspection first were determined conditions of the inner surface of the sewer. Furthermore, a destructive method, *i.c.* core sampling, was applied to determine the strength properties of pipes through mechanical testing of samples.

2.1 Visual inspection

For this study, a commercial waste management company, was assigned to conduct inspection with CCTV. The manner in which visual inspection needs to take place and assessment of deterioration conditions is firmly established in the guidelines of Sewage system, operations management, C2400 module (Chan 2011). The registration of defects was done according to the NEN-EN 13508-2 (Nederlands Normalisatie-instituut 2003) and the NEN 3399 (Nederlands Normalisatie-instituut 2004a). All inspection reports have to go through a re-evaluation by the inspector from the Municipality of The Hague who makes the final decision on the existing sewer condition.

The most common condition aspects of sewer systems noted by the municipality of the Hague are: surface damage (BAF) and crack (BAB). Table 1 shows the action plan under different sewer conditions. It should be noted that replacement decisions and/or additional investigation is the method used within the Municipality of Hague and it is not completely in line with the NEN 3398 norm (Nederlands Normalisatie-instituut 2004b). This study focused only, due to good soil conditions, on the surface damage classification. At the places where there is estimated more than 50% of severe surface damage (class BAF 4) drill core samples are taken (Chan 2011).

Table 1. CCTV classification for BAF/BAB with associated action (Chan 2011).

Classification	1	2	3	4	5
BAF	no	no	no	drill core	replacement
BAB	no	no	no	replacement	replacement

In addition, the surface damage of core samples was also estimated during overall drill core analysis in VLG Laboratory of the municipality of Rotterdam.

2.2 Drill core analysis

In each section between two manholes four core samples of 100 mm diameter were taken by the contractor Meeuwisse Nederland BV. The cores are taken by drilling directly from the street. The samples were transported to the VLG laboratory of the municipality of Rotterdam and tested for splitting tensile strength, specific mass and water absorption so the quality of the concrete could be determined. All tests mentioned were carried out according to standard NEN-EN 12390 "Testing of hardened concrete" (Nederlands Normalisatie-instituut 2009). Core classification was based on the INTRON (Institute for materials and environmental research) report (INTRON 1997). Table 2 shows the classification applied in the Hague. The final core classification is based on the highest score of the three criteria shown in Table 2. Sewer replacement is scheduled only for the pipes classified as class 5, (Chan 2011), *i.e.* when one of the criteria is five.

Table 2. Drill core classification according to "The Hague" (Chan 2011).

	class 1	class 2	class 3	class 4	class 5
Splitting tensile strength (N/mm^2)	>6	5-6	2.6-4.9	2.5-2	<2
Water absorption (%)	<8	8-9	9-11	11-13.5	>13.5
Specific weight (kg/m^3)	>2275	2230-2275	2190-2229	2150-2189	<2150

Statistical analysis was carried on the experimental result. To determine the homogeneity and independence of the core results, non-parametric statistical test of Mann-Whitney and Wald-Wolfowitz were used.

3 RESULTS AND DISCUSSION

Firstly, sewer condition - surface damage was assessed by CCTV over the whole studied length. Figure 1 shows the inspection results from 2006 and results with re-evaluation from 2011 at the studied location. From the results it can be seen, that CCTV results from 2006 are one class lower in comparison to CCTV results from 2011. This implies that the sewer deteriorated over time which is to be expected due to aging of the sewer (Sousa et al. 2009). However, results from 2011 are not entirely in line with the re-evaluated results from 2011. *E.g.* in sections 1 and 2 surface damage was differently estimated by field inspector (results) and the municipal inspector (re-evaluated results). The results suggest that subjective visual assessment introduces uncertainties in the overall surface damage assessment confirming earlier research (Dirksen et al. 2011).

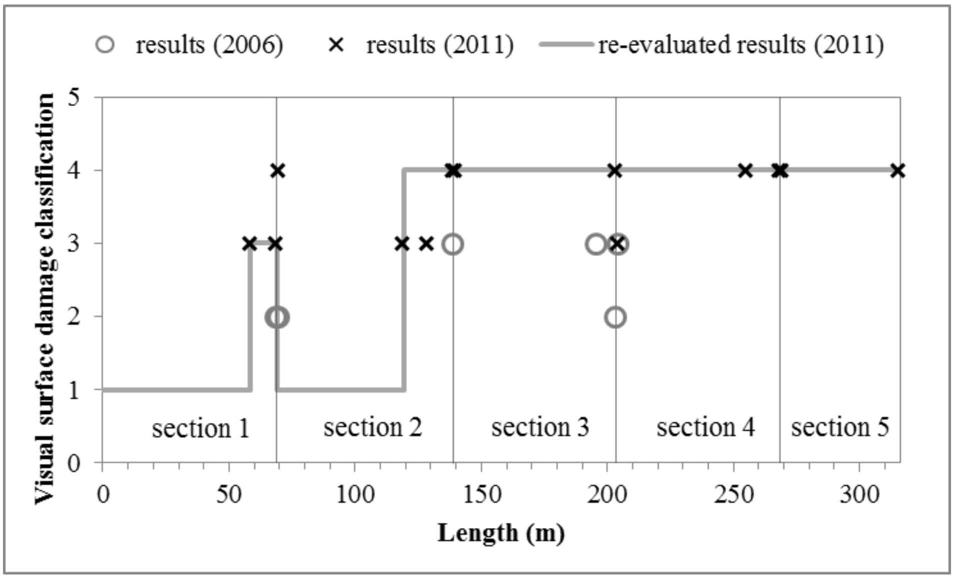


Figure 1. Classification of visual impairment conditions using CCTV at the studied location as a function of time.

Also visual estimation of surface damage was done in the laboratory on collected drill core samples. From Figure 2 it can be seen that the laboratory results do not entirely support CCTV results. According to the laboratory results, no serious surface damage was observed on the bottom of sewer, but this was not the case with CCTV results. Comparing laboratory results of samples from the top of sewer and CCTV results, the only similarity between results is in the section 3. Also in this case it should be noted that subjective assessment of a small surface area (core samples) in comparison to an overall surface area introduces uncertainties in the overall condition assessment.

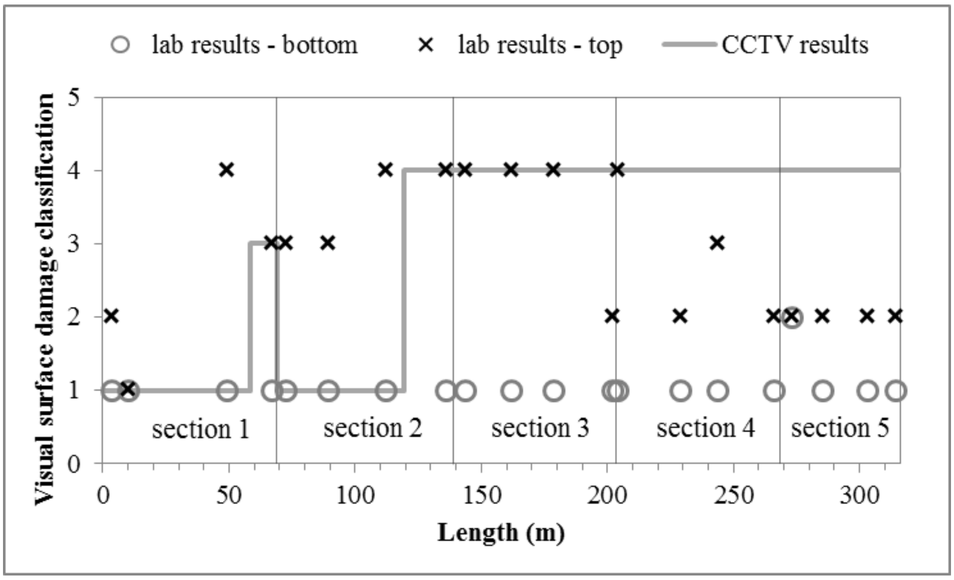


Figure 2. Comparison of CCTV and laboratory visual inspection results over studied sewer length

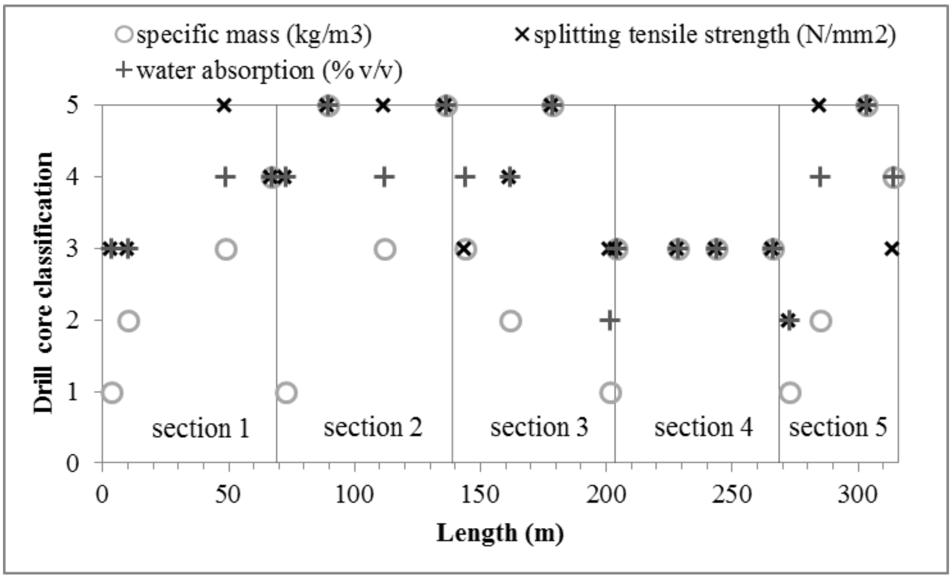
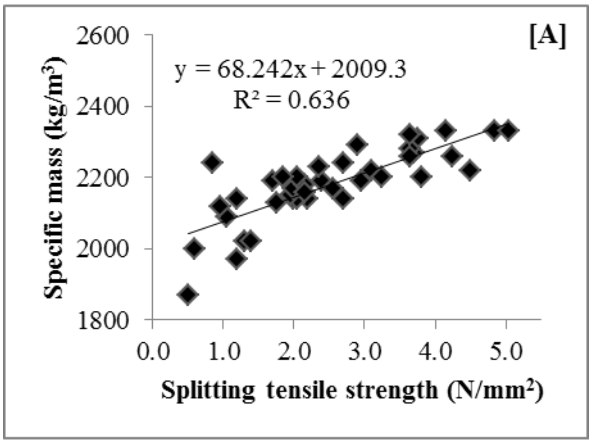
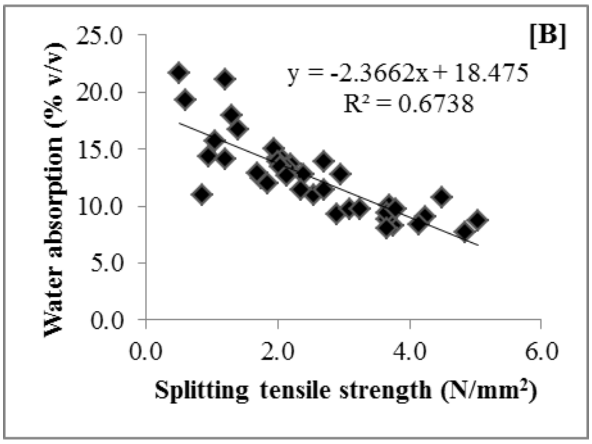


Figure 3. Classification of the experimental results of core sample from the top of sewer at the studied location.

Secondly, sewer conditions were assessed based on the experimental results of core samples taken on selected locations. From the results (Figure 3) it can be seen, that there is a significant variation in classification between parameters selected by the Municipality of The Hague. *E.g.* in the section 2 and 5 can be seen that the difference between specific mass and splitting tensile strength is 3 classes. As mentioned earlier, core classification is based on the criterion with the highest score. This implies that classification results could be changed with the exclusion of even one parameter. For example, if the results of splitting tensile strength were excluded the classification results would change.

The experimental results of specific mass, water absorption and splitting tensile strength were analysed on the presence of mutual correlation. The coefficients of determination (R^2) given in Figure 4 A-B show that there was no obvious correlation between specific mass and splitting tensile strength results and between splitting tensile strength and water absorption results. On the other hand, the correlation coefficient (Figure 4 C) suggests that values of specific mass and water absorption are interdependent. Therefore according to studied correlations, core conditions could be assessed with either studying specific mass or water absorption due to the fact that they are correlated, or they could act as control measurement.





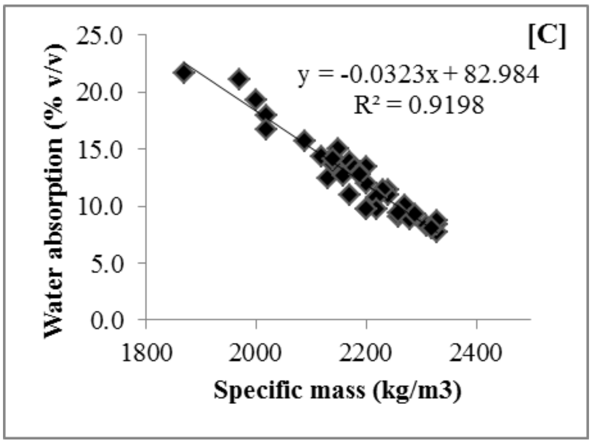


Figure 4. Correlation between: [A] specific mass and splitting tensile strength results. [B] Splitting tensile strength and water absorption results. [C] Specific mass and water absorption results.

As mentioned earlier, core samples were taken from the bottom and the top of the sewer at the studied location. Experimental results showed (Table 3) that bottom samples had lower average density and a higher water absorption. This suggests that the specific mass of concrete on the sewer bottom decreased over the years and deteriorated more than the top of the sewer. Most likely the durability of concrete was influenced by some unknown process.

Before conducting any statistical analysis on the experimental results first was necessary to determine their independence and homogeneity. The non-parametric statistical test of Wald-Wolfowitz and Mann-Whitney confirmed that the results are independent and homogeneous.

Table 3. Statistical characteristics of the selected core parameters from bottom and top of sewer at the studied location with average classification value.

	Sample thickness (mm)		Specific mass (kg/m^3)		Splitting tensile strength (N/mm^2)		Water absorption (% v/v)	
	bottom	top	bottom	top	bottom	top	bottom	top
μ	64.3	66.0	2164.5	2198	2.45	2.59	13.35	11.68
S_d	2.0	2.2	119.80	81.21	1.24	1.18	4.03	2.59
C_v	0.03	0.03	0.06	0.04	0.50	0.46	0.30	0.22
C_s	0.81	0.23	-0.75	-0.73	0.35	0.31	0.57	0.94
$class_{avg}$	-	-	4	3	4	3	4	4

Legend: μ – average S_d – standard deviation C_v – coefficient of variation C_s – skewness
$class_{avg}$ – average classification over the sewer length

From Table 3 also a couple of other observation can be made. Firstly, that variation of sample results from the sewer invert was higher in comparison to results from the top. This could imply that concrete on the invert had more non-constant deterioration in time than on the top. In addition, skewness showed that there was non-constant deterioration of the concrete over the length of the studied sewer. Coefficient of variation had the highest value for the results of splitting tensile strength test. This high deviation was probably influenced by several factors. Non-uniform deterioration over time influences the results of splitting test. Another influencing factor on the recorded strength is height/diameter ration of the cylinder which was in studied case lower than 1 suggesting that results were unreliable (Neville 1995). Also, it should be emphasized that the core strength, even under excellent experimental conditions, is unlikely to exceed 70-85 % of standard test specimens (Neville 1995). Moreover, based on the previous testing of the laboratory the uncertainty of the splitting tensile strength results is 2 N/mm^2. When this is compared with the average values of the splitting tensile strength given in the Table 3, it can be seen that uncertainty of the results is high. Consequently, when considering all these different factors it could be considered that results of the splitting tensile strength are unreliable.

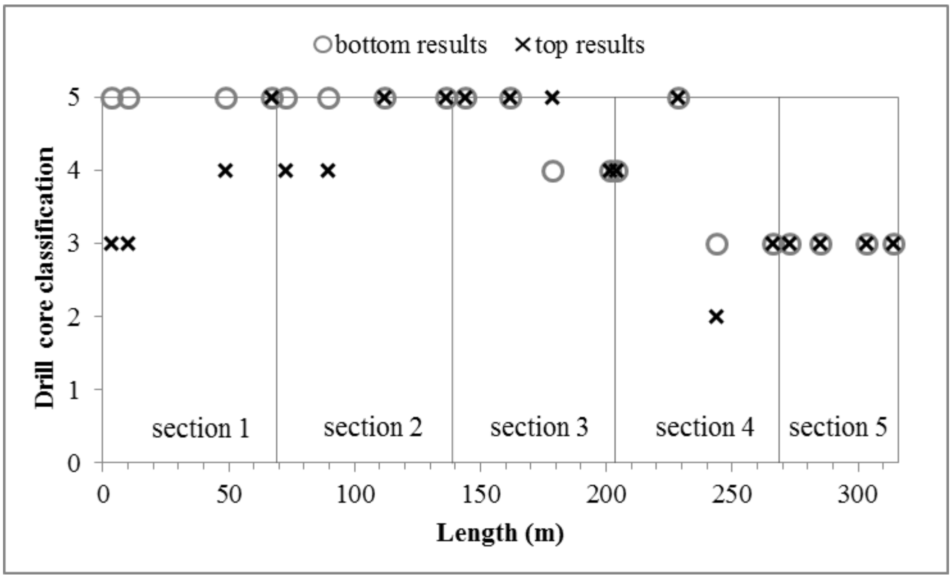


Figure 5. Comparison of drill core sample results from sewer invert and top at the studied location.

It is noted that there is a difference in condition assessment between bottom and top of sewer (Figure 5). A general assumption is that concrete on the top part of sewer has poorer quality then the concrete on the bottom due to the classical H_2S induced crown corrosion process (Bielecki and Schremmer 1987), and based on this implicit assumption the current condition assessment is done in practise. Results showed that concrete conditions at the sewer invert were more severe than conditions at the top of sewer. This contradicts the general idea of sewer corrosion being dominantly caused by biological H_2S, which typically affects the top. Therefore, more attention should be given to the sewer bottom in future practise.

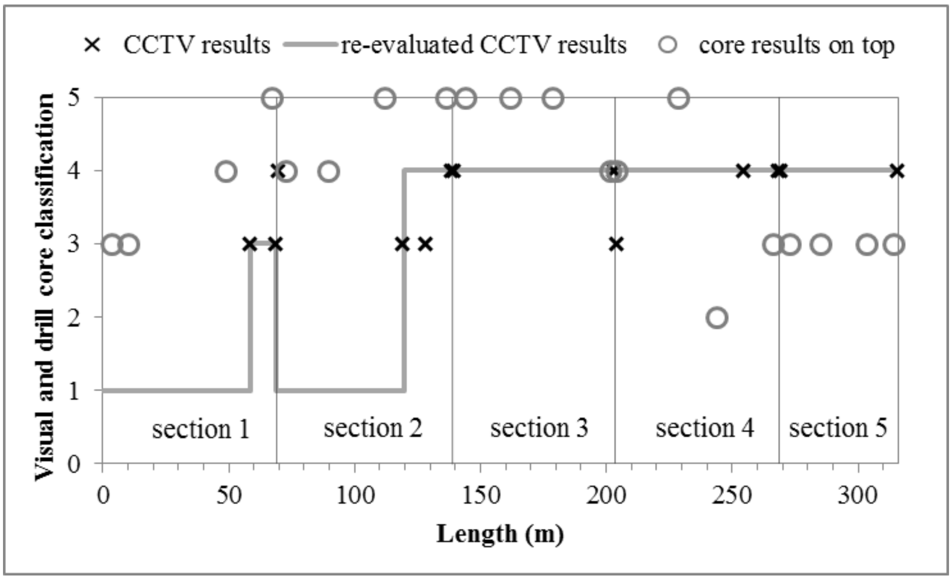


Figure 6. Comparison of visual inspection and drill core analysis results at the studied location on which is based final conditions assessment.

In the municipality of the Hague final sewer condition assessment is based on the re-evaluated CCTV results and drill core experimental results from the top part of sewer. Figure 6 shows the difference in estimation of current conditions at the studied location. Based on current Hague inspection regulation section 2-3 and one part of section 4 should be replaced. On the other hand, sewer conditions in the section 5 are better while looking at the core results. Furthermore, re-evaluated CCTV results are not in line with that drill core results. *E.g.* re-evaluated CCTV and drill core results have the same values only in the area between section 3 and 4.

4 CONCLUSIONS

This study was carried out to further understand the limitations and potentials of both visual inspection and drill core analysis. The following conclusions transpired from the study.

- Laboratory visual assessment of core samples and CCTV visual assessment of sewer condition showed that classification can differ due to the different size of the observed surface area and subjective assessment.
- Core classification is based on criteria parameters. The quality of final core classification depends on selection of parameters and their classification range.

- Concrete conditions could be assessed with either specific mass or water absorption due to their correlation.
- Concrete deteriorated non-uniformly in time and over the length of the studied location.
- Different factors like non-uniform deterioration, height/diameter ratio, experimental uncertainty and damage during drilling influence the proper estimation of the splitting tensile strength which makes results unreliable.
- The quality of concrete at the sewer bottom was systematically lower in comparison to the concrete quality at the top of sewer.
- There is no obvious correlation between results of visual inspection and results of drill core analysis.

Overall, the understanding of uncertainty of inspection data is relevant for future decision making and model development. Uncertainties related to application of both CCTV inspection and core analysis in today's practice could be decreased. Proper selection of core classification parameters and their classification range will provide more reliable results. Further, core should not be damaged during collection and they should have proper dimension. Moreover, current core sampling method is more suitable for the pipes of bigger diameter due to available drill sizes in practice. This is a first step towards identification of uncertainties in results of inspection methods.

5 ACKNOWLEDGEMENT

The authors would like to acknowledge the funding by (in alphabetical order) ARCADIS, DHV, Gemeente Almere, Gemeente Breda, Gemeente 's-Gravenhage, Gemeentewerken Rotterdam, GMB Rioleringstechnieken, Grontmij, KWR Watercycle Research Institute, Royal Haskoning, Stichting RIONED, STOWA, Tauw, Vandervalk & De Groot, Waterboard De Dommel, Waterboard Vallei & Eem, Waternet and Witteveen+Bos as part of the Urban Drainage Research program.

In addition, authors would like to acknowledge the help of Steven Chan, Willem Oldenhave, Robert Bleiksloot, Martijn Klootwijk and Kees Hufen in sharing of knowledge.

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