Design Of A Laboratory Set-up For Evaluating Structural Strength Of Deteriorated Concrete Sewer Pipes

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ABSTRACT
The principle of structural behaviour of buried concrete pipes is fairly understood, except for how material deterioration affects structural behaviour and performance. Consequently, information on the structural behaviour of deteriorated sewer pipes will contribute to better understanding of the changes in status, which is essential for achieving the desired efficiency gains for urban drainage systems. In literature, some attempts to study the behaviour of the buried pipes under laboratory conditions have been reported. However, no attempt was made to evaluate the structural response of deteriorated concrete sewer pipes. The paper describes the design of a laboratory set-up for evaluating the strength of deteriorated sewer pipes. The test setup is a representation of field conditions in order to see if it is possible to model the field condition. Overall, this research is a first step in determining the probability of collapse of deteriorated sewer pipes that will enhance proper decision making for sewer rehabilitation.

KEYWORDS
Concrete sewer; destructive test; experiment setup; sewer pipes; structural strength;

INTRODUCTION
High quality information on the actual status of the assets is a prerequisite for adequate sewer asset management. Currently, pipe age and visual sewer inspection are typically the primary sources of information used for decision making for sewer rehabilitation (Halfawy *et al.* 2008). Dirksen *et al.* (2013) have shown that visual inspections have a significant uncertainty. Besides, visual inspection will not reveal invisible deterioration, like corrosion on the outside wall of a sewer. As a result, it is not possible to derive the remaining strength of a sewer pipe using CCTV inspection data only. Destructive methods like core sampling can provide additional valuable information about the wall thickness and material properties of the pipe material.

The principle of structural behaviour of buried concrete pipes is fairly well understood, except for how material deterioration affects structural behaviour and performance. Consequently, information on the structural behaviour of deteriorated sewer pipes will contribute to better understanding of the changes in status, which is essential for achieving the desired efficiency gains for urban drainage systems. Therefore, it is necessary to define a new method that will be able to collect this information.

In literature, some attempts to study the behaviour of the buried pipes under laboratory conditions have been reported so far (Trautmann and O'Rourke 1985; Brachman *et al.* 2000). However, no attempt to evaluate the structural response of deteriorated concrete sewer pipes under laboratory conditions has been reported. Consequently, information on the structural behaviour of deteriorated sewer pipes will contribute to better estimate the probability of collapse of sewer pipes.

The paper describes the design of a new laboratory set-up for evaluating the performance of buried and degraded sewer pipes. The test setup is a simplification of actual field conditions and will be used to verify a numerical model (still to be made). Once the model is made an accurately predicts the structural behavior of a sewer pipe, the structural behavior of these pipes can be studied in more depth, e.g. taking the soil conditions into account. The final model can be used to determine the remaining load bearing capacity of a sewer pipe or can be used in order to determine the type of information needed to make that decision (reversed engineering).

MATERIALS AND METHODS

The study was conducted on excavated sewer pipes that were scheduled for replacement, according to the municipal sewer rehabilitation plans of The Hague and Breda. Prior to excavation visual inspections were performed to determine the condition of the inner surface of the sewer *i.e.* surface damage by internal chemical (corrosion) or mechanical action (BAF). The registration of defects was done according to the visual inspection coding Standard NEN-EN 13508-2, while the Standard NEN 3399 was used to assign a level of severity to each defect – condition assessment (Nederlands Normalisatie-instituut 2003; 2004a).

Pipes from both municipalities are from combined sewer systems; they are egg-shaped with dimensions of 400/600 mm, 1m long and made of concrete. The sewer in The Hague is located in a domestic housing area around old dunes. In this area the groundwater is below the sewer invert level (Gemeente Den Haag 2011). The area in Breda used to be partly industrial and partly domestic. As a consequence, the Breda sewer was under a constant high traffic load for approximately 35 years. In this area, the groundwater is above the sewer crown level and the surrounding soil is a combination of peat, clay and sand (Oranjewoud 2009). Furthermore, a new concrete sewer pipe egg-shaped with dimensions of 400/600 mm, from De Hamer factory, was used to validate the experimental results. The new pipe was 2 m long, being shortened to 0.85 m length to allow testing in the same test facility. The quality and the shape of the new pipe meets the requirements required by the Netherlands and European standards NEN 7126, NEN-EN 1916 (Nederlands Normalisatie-instituut 2002; 2004b). A detailed characteristic of each pipe is given in a Table 1.

Table 1. Characteristics of studied sewer pipes.

No.	Origin	Age	Surface damage class (BAF)	BAF class description
1	De Hamer factory	new	-	
2	The Hague	1924	4	Missing aggregates or reinforcement outside the surface protrudes
3	The Hague	1924	4	
4	Breda	1952	3	Aggregates that protrude beyond the surface or visible reinforcement
5	Breda	1952	3	

Laboratory test set-up

Boundary conditions. The first step considered in the design of the laboratory set-up involved simplification of boundary conditions experienced by an underground pipe . The structural performance of the pipe is a function of both the soil and pipe stiffness and the resulting soil-structure interaction. Pressures arise at the boundaries of the soil–pipe system. These pressures have a vertical component σ_v arising from the weight of the overlying materials above the pipe and a horizontal component σ_h associated with the restraint against lateral soil movement within the embankment.

In the setup design hypothetical soil properties were assumed (Young's modulus E = 80 MPa, Poisson's ratio ν = 0.25, angle of internal friction φ = 40°, angle of dilatancy $\psi = \varphi/4$, cohesion c = 0, and unit weight γ = 18 kN/m^3) (Brachman *et al.* 2000). Further, horizontal stresses are expressed as $K\cdot\sigma_v$, where $K = \nu/(1- \nu) = 0.33$ is the coefficient of lateral earth pressure. This is a laboratory idealization of field conditions. The applied experiment principle is shown in Figure 1 (left).

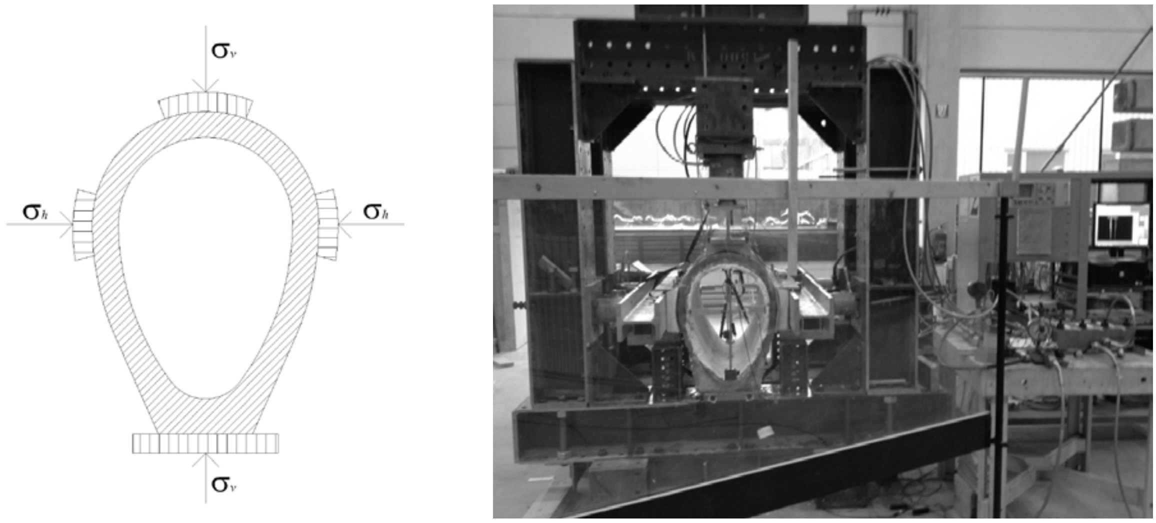
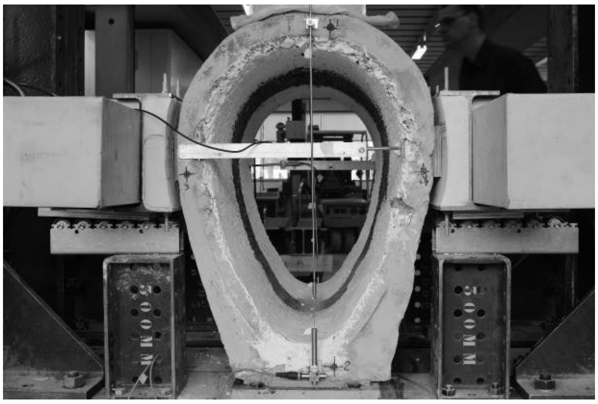


Figure 1. The schematic diagram of adopted experiment principle (left) and actual experimental setup (right).

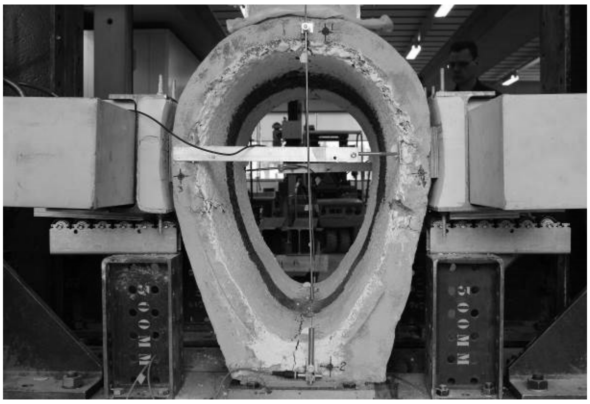
Design. The experimental setup (Figure 1, right) consists of a test cell (steel frame/beams) and a concrete, egg shaped sewer pipe. Applying a uniformly distributed pressure at the crown of the pipe may reasonably represent the vertical stress from the weight of the overburden material. As a reaction vertical stresses are present at the invert level of the pipe. Horizontal stresses could be simulated in a similar manner by applying lateral pressures equivalent to the horizontal stresses generated in the field. The pipe was stressed using a system of oil pressure jacks and steel beams. In order to achieve a uniform distribution of stresses plaster moulds of pipe and soft boards were attached to the steel beams. The size of the load bearing plates is 1.5 time of the pipe thickness. The tests were carried out at a loading rate of 10 kN/min. Sewer pipes were loaded in the set-up till the point of the pipe collapse. Vertical and horizontal load were measured together with their front and back vertical/horizontal displacements.

RESULTS AND DISCUSSION

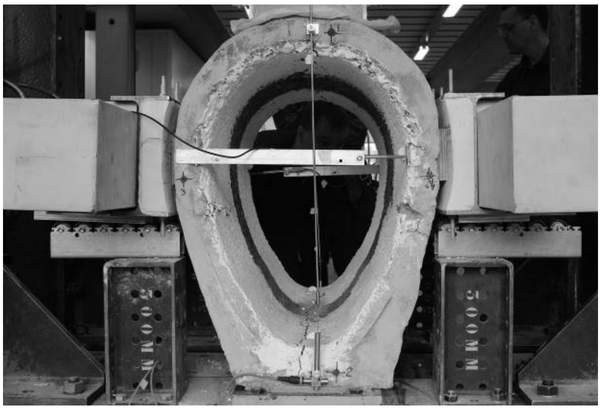
For all pipes cracks appeared at the same location suggesting that the distribution of stresses through the pipes during the tests was the same. The first crack always appeared at the pipe invert level, followed by cracks at the pipe crown area and one on each side (Figure 2). It was followed by the crack at crown of the pipe and further by cracks on both sides of the pipe.



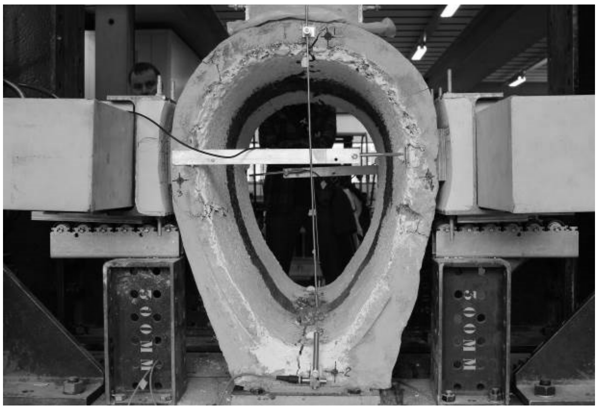
a. F_v = 130.1 kN



b. F_v = 145.9 kN



c. F_v = 165.8 kN

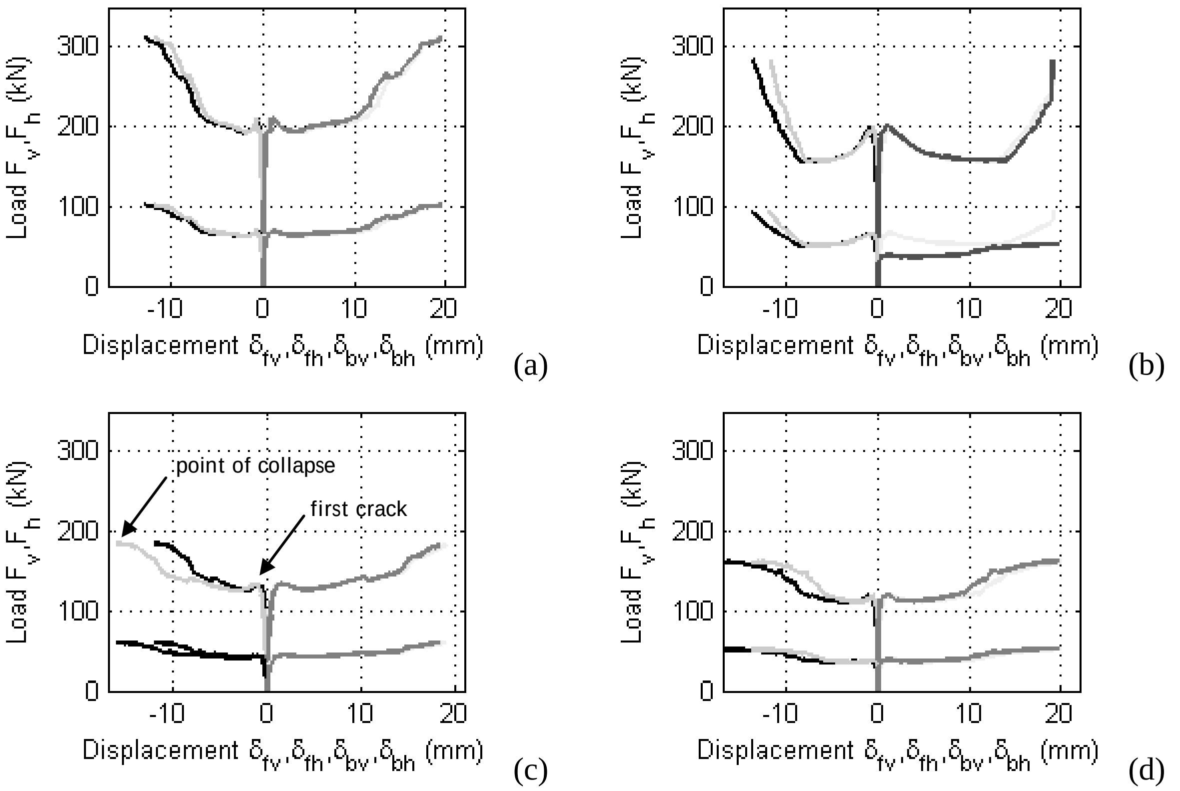


d. F_v = 181.5 kN

Figure 2. Successive stages in the test of a sewer pipe from Municipality of The Hague during the experiment.

Figure 3 shows load-displacement response for the studied pipes. The results show clearly the regions of crack formation and points of the pipe collapse. Major cracks on the new pipe appeared at the vertical load, F_v = 280 kN. The major cracks on the 60 and 90 year old pipes appeared at around 25% and around 55% smaller load. With an increase of the load, however, the pipes resisted collapse due to the combination of vertical and horizontal loads.

Test results showed that the new pipe was able to withstand a load up to 330 kN. Also, results showed that the 60 year old pipes could withstand almost the same amount of load, F_v = 315 kN and F_v = 290 kN. In contrast, the 90 year old pipes could withstand a load up to 185 kN and 162 kN (around 40% less stress). This implies that pipes, that are considered old (60 year old), can withstand similar loads as a new pipe. Consequently, when considering all these results, it could be regarded that pipe age, the main information source in deciding upon sewer system renewal (van Riel *et al.* 2014), is unreliable. Furthermore, from the results it can be seen that the first cracks occurred with displacement of about 0.6 mm, and that the pipes reach the point of collapse with displacements between 13 and 19 mm.



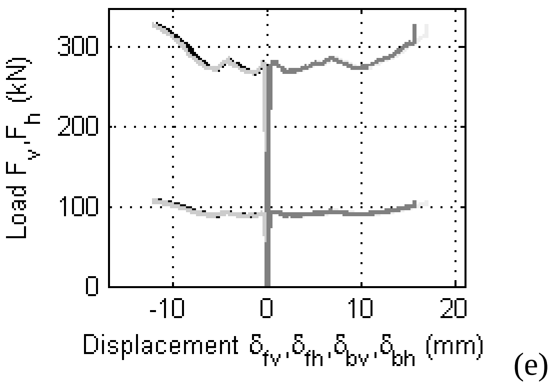


Figure 3. Force-displacement response for; (a,b) the 60 year old sewer pipe; (c,d) the 90 year old sewer pipe; (e) the new sewer pipe;.

Legend:
F_v – vertical force; F_h – horizontal force; δ_{fv} – front vertical displacement; δ_{fh} – front horizontal displacement; δ_{bv} – back vertical displacement; δ_{bh} – back horizontal displacement.

The test method for the crushing strength of new concrete pipes is defined by standards NEN 7126 and NEN-EN 1916 (Nederlands Normalisatie-instituut 2002; 2004b). For the egg-shaped pipes with flat base, the uniaxial load shall be applied through one top bearer and they shall be supported on two bottom bearers placed with their centres at a distance equal to 0,3 times the internal diameter or width. De Hamer concrete factory performs these quality check test regularly and they get an average value of 131 kN for the pipe crushing strength. This crushing strength is about 60% smaller than the experimental setup recorded crushing strength. This result was to be expected, as the horizontal support in the experiments has a strong impact on the strength of the pipe.

Figure 4 shows the four-point flexural tests results from the accompanying research by Stanić *et* al. (in preparation) that contributes to better understanding of structural status. The tests have been performed in order to get a first impression whether or not the structural properties of the concrete are still homogeneous over the thickness of a wall. The four-point flexural tests were carried out on rectangular samples (with dimension of 105 mm x 62-75 mm x 480 mm) taken from the upper and lower part of broken pieces of the pipes. Results showed that there is no consistency between the experimental results for the new pipe and the 90 year old sewer pipe. This can be explained by the fact that the tested beams were not completely rectangular due to the shape of the pipes. In addition to the irregular shaped beams, the 90 old pipe did not deteriorate uniformly, thus making these results more inconsistent. Furthermore, the initial quality of the concrete is not the same for the studied sewer pipes. There is no recorded information on the quality of the studied old concrete sewer pipes.

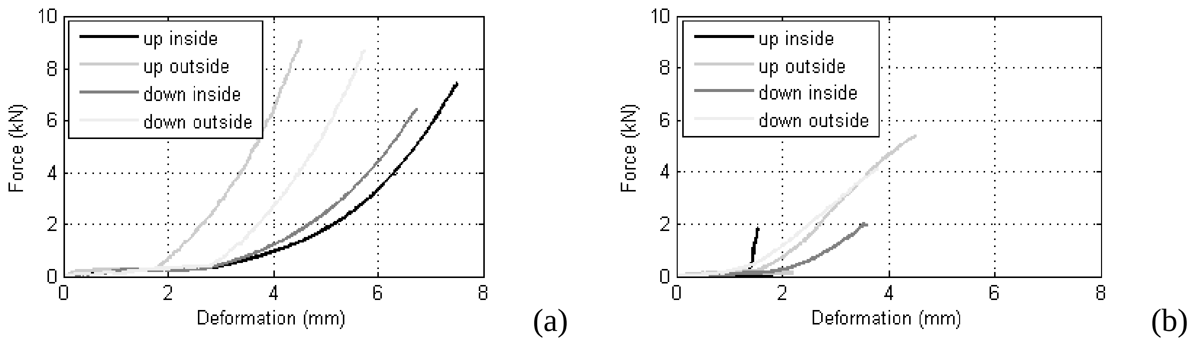


Figure 4. The four-pint flexural test force-deformation response for; (a) the new sewer pipe; (b) the 60 year old sewer pipe.

CONCLUSIONS

Sewer systems deteriorate due to aging, overloading, misuse and mismanagement. It is not clear, however, when exactly pipe approaches the end of its useful life. Results suggest that pipe age and CCTV as main information source in deciding upon sewer system renewal (van Riel *et al.* 2014), are insufficient. Therefore, there is a need for a change in current sewer inspection strategies. Further, flexural test showed that concrete deteriorated non-uniformly in time and over the length which was also shown in Stanić *et* al. (2013) . Moreover, the presence of cracks does not imply that the pipe will collapse. Cracked pipes could withstand reasonable additional load. Different factors, like road conditions, traffic load and especially local soil conditions may influence the sewer's lifespan. System can with stand certain amount of load but with deterioration boundaries of acceptable load changes.

The manner in which the quality check test is carried out, based on standards, showed that the new pipe has smaller load bearing capacity than the pipe that is in addition burdened horizontally (which represents a more real conditions). The buried pipe act as a component of the soil–pipe system with pressures at its boundary, which in addition to a vertical have a horizontal component. Therefore, it is necessary to revise the currently applied quality check standards.

Overall, this research is a first step in towards the model development which will enable prediction of collapse of deteriorated sewer pipes that will enhance proper decision making.

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