REPLACEMENT PIPE DEFLECTIONS UNDER VERTICAL PRESSURE

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ABSTRACT
Measurements of vertical and horizontal pipe deflections are reported for an HDPE pipe experiencing an increase in vertical pressure after being pulled in place using a pipe bursting technique. Three tests measured the diameter change of an HDPE pipe after replacing an intact clay pipe with an external diameter of 184 mm while a fourth test measured diameter change of a HDPE pipe under increasing vertical pressure after replacing an intact clay pipe with external diameter of 128 mm. Varied pipe deflections were measured in each test which is attributed to the presence of broken clay fragments surrounding the HDPE pipe. In some cases the fractured clay pipe was found to provide additional structural support for the new HDPE pipe. It was found that in addition to the stiffness of the new pipe and backfill soil, the deflections of the new HDPE pipe also depend on cavity expansion and contraction of the soil surrounding the pipe from the pipe bursting process and interactions between remnant clay fragments.

RÉSUMÉ
Des mesures de déflexions verticales et horizontales sont rapportées pour un tuyau de PEHD éprouvant une augmentation de pression verticale après avoir été mis en place par la technique d'éclatement de conduite. Trois essais ont mesuré le changement de diamètre d'un tuyau de PEHD après le remplacement d'un tuyau d'argile de diamètre extérieur de 184 mm remblayé avec du sable dense mal gradué. Un quatrième essai a mesuré le changement de diamètre d'un tuyau de PEHD sous une pression verticale croissante après le remplacement d'un tuyau d'argile de diamètre extérieur de 128 mm remblayé avec du sable dense mal gradué. Des déflexions variées qui sont attribuées à la présence des fragments cassés de tuyau d'argile entourant le tuyau de PEHD, ont été mesurées dans chaque essai. Dans certains cas le tuyau d'argile fracturé s'est avéré l'appui structural additionnel pour le nouveau tuyau de PEHD. Il est constaté qu'en plus de la rigidité du nouveau tuyau et du sol, les déflexions du nouveau tuyau de PEHD dépendent de l'expansion de la cavité et de la contraction du sol entourant le tuyau provenant du processus d'éclatement de conduite et les interactions entre des fragments d'argile.

1. INTRODUCTION

Pipe bursting is a construction technique where a deficient buried pipe (either structurally deteriorated or hydraulically undersized) is replaced with a new pipe without the need for a cut-and-cover excavation along the pipeline. The new replacement pipe is pulled into placed following a bursting head that breaks and displaces the original (or replaced) pipe.

Ground displacements and pulling forces associated with pipe bursting have been previously examined using numerical techniques and large-scale physical testing (e.g., Fernando and Moore, 2002; Lapos et al., 2004). However, the structural response of a pulled-in-place pipe via pipe bursting when subjected to additional vertical pressure (e.g., construction of an embankment on top of the replaced pipe) has not yet been examined. The physical response of a buried pipe to increases in vertical pressures is normally a function of the stiffness of the pipe and the soil and the corresponding interactions between the two. For a pulled-in-place pipe, it may be hypothesized that expansion and contraction of the soil cavity during installation and possible interactions between remaining fragments of the original pipe also influence the structural response of the new pipe.

In this paper, results are presented from four large-scale experiments conducted to examine the deflections of a high density polyethylene (HDPE) replacement pipe (outside diameter of 165 mm and wall thickness of 10 mm) under applied vertical pressures up to 200 kPa.

2. EXPERIMENTAL DETAILS

Tests involving increased vertical pressure on a pulled-in-place HDPE pipe were conducted with the apparatus developed by Brachman et al. (2001). The apparatus is 2 m wide by 2 m long by 1.6 m deep. Vertical pressures up to 1000 kPa can be simulated using a pressurized rubber bladder across the top surface. Horizontal stresses are generated by limiting the deflections of the apparatus with stiff side walls. A cross-section through the apparatus is shown in Figure 1.

Four tests were conducted on an HDPE pulled-in-place pipe by pipe bursting. Tests 1 to 3 involved replacing an intact clay pipe with external diameter of 184 mm and thickness of 19 mm with an HDPE pipe with external diameter of 165 mm and thickness of 10 mm. Since the internal diameter of these pipe are essentially the same, Tests 1-3 will be referred to as replacement tests. In Test 4 a smaller intact clay pipe with external diameter of 128 mm and thickness 14 mm was replaced with the same HDPE pipe. Since the diameter of the HDPE test is 50% larger than the clay pipe, Test 4 will be referred to as an upsizing test.

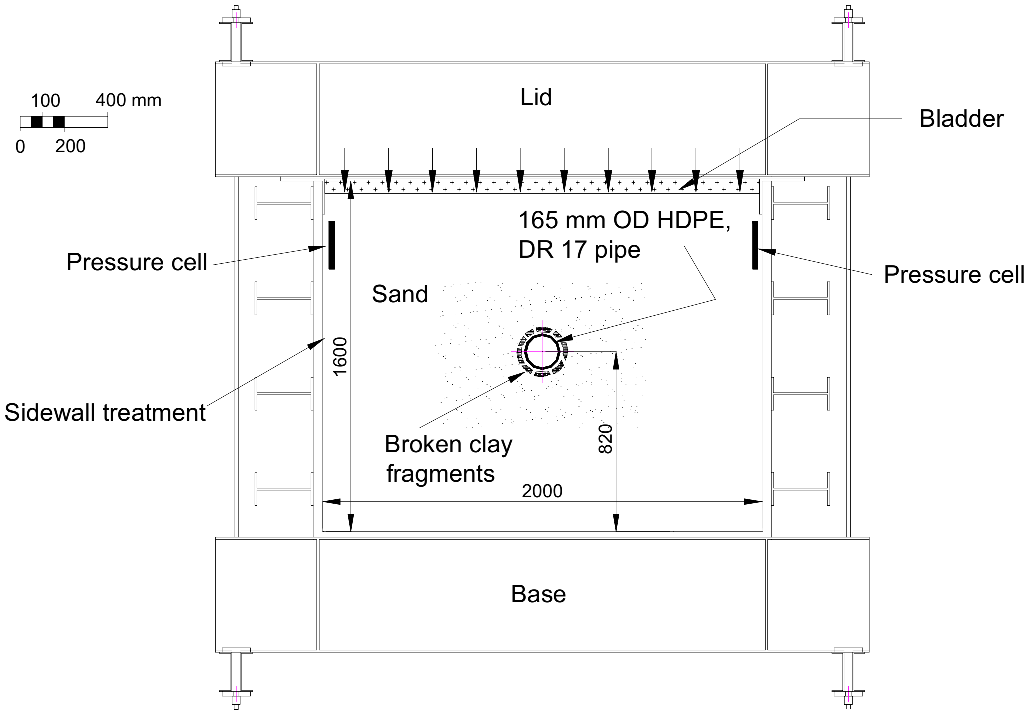


Figure 1. Cross-section through test apparatus (dimensions in mm).

The laboratory procedures for pulling the new HDPE pipe in place have been described elsewhere by Lapos et al. (2004). After completion of the bursting operation the apparatus lid was bolted into place so additional vertical pressure could be applied. To minimize the effect of boundary friction, grease applied between two polyethylene sheets was placed between the soil and apparatus walls (Tognon et al., 1999). The backfill material used in each test was Synthetic Olivine, a poorly-graded sand with a maximum dry density of 1.5 g/cm^3 and internal angle of friction of 44º. The sand was placed in 250 mm thick lifts and compacted by dropping a 6.8 kg mass a height of 0.3-0.4 m. Soil density was recorded using a nuclear density meter and the dry density and water content for each test are summarized in Table 1.

With the apparatus lid secured in place, the vertical pressure was applied following the procedures described by Brachman et al. (2001). The vertical pressure was applied rapidly in load increments of 20 kPa and then held constant for 12 minutes. All four tests were loaded to a maximum vertical pressure of 200 kPa.

Deflections of the HDPE pipe were measured with linear potentiometers. Figure 2 shows the location of deflection measurements relative to the centre of the pipe. Deflections were measured at Section 3 for Tests 1 and 2, while measurements were made during Tests 3 and 4 at the four sections shown in Figure 2. At each section the vertical and horizontal diameter change of the pipe was recorded. The relatively close spacing of the measurements was intended to investigate any local variations in deflection resulting from pipe interaction with the remnants of the clay pipe.

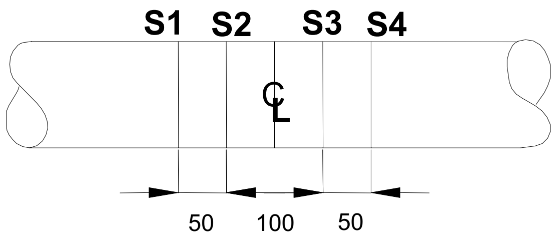
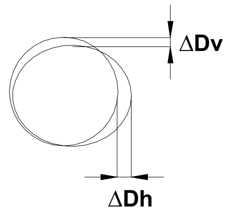


Figure 2. Location of displacement measurement sections relative to pipe centreline (dimensions in mm).

3. RESULTS

3.1 Measured deflections

The measured vertical and horizontal deflections of the pipe for Tests 1-3 are plotted in Figure 3. As expected, the pipe experiences a general decrease in vertical diameter (i.e. negative diameter change) and increase in horizontal diameter when subject to the increase in vertical pressure. However, the development of pipe



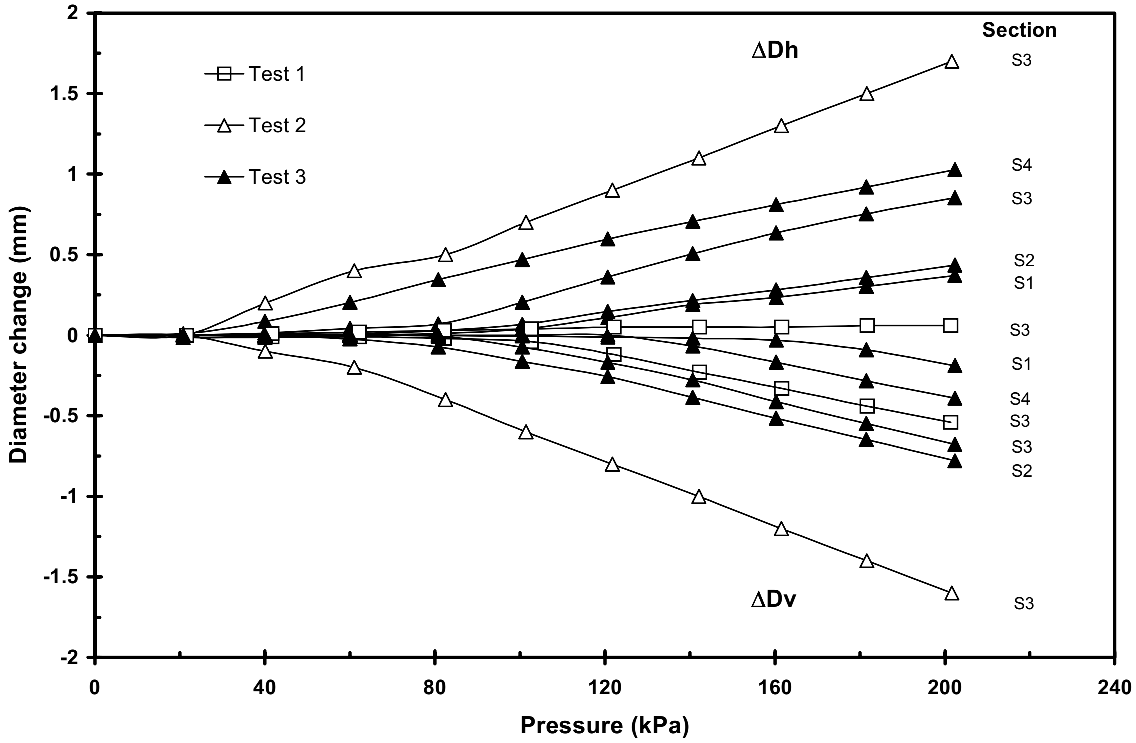


Figure 3. Measured vertical and horizontal diameter change from replacements tests 1, 2, and 3.

deflections during these test differs from previous experiments on similar HDPE pipes that did not involve pipe bursting. For example, most of the measurements in Figure 3 show very small deflections to 80-100 kPa that subsequently increase at higher pressures, whereas experiments not involving pipe bursting produce linear and monotonic increases in deflection with pressure (e.g., see Brachman et al., 2001). The cavity expansion and contraction process from pipe bursting and/or effects from the remnant clay fragments are possible explanations for the observed delay or offset in pipe deflection response.

The deflections are also much more variable for the pipe installed using pipe bursting than previous experiments without pipe bursting. The vertical diameter change varies between -0.2 and -1.5 mm at 200 kPa for Tests 1-3, as shown in Figure 3. Without pipe bursting, measured deflections at duplicate sections were essentially identical for similar sand backfill (Brachman et al., 2001). The variations observed in Figure 3 are possibly due to the presence of clay fragments around the pipe, which will be examined further using visual observations in the next section.

As expected from identical test setups, the vertical diameter change from Test 1 lies within the range of values from Test 3. Although the three experiments were conducted in essentially the same manner, the measured deflections in Test 2 are larger and appear to start to increase sooner than those recorded during Tests 1 and 3. It is believed that the differences in pipe deflections between Tests 1 and 3, and Test 2 arise from the nature of the broken fragments of the original clay pipe. Visual observations presented in the next section will be used to further investigate the effect of broken clay fragments on the response of the HDPE pipe.

The vertical and horizontal diameter change of the pipe from upsize Test 4 is plotted in Figure 4. The vertical diameter change varies between -0.9 and -1.5 mm at

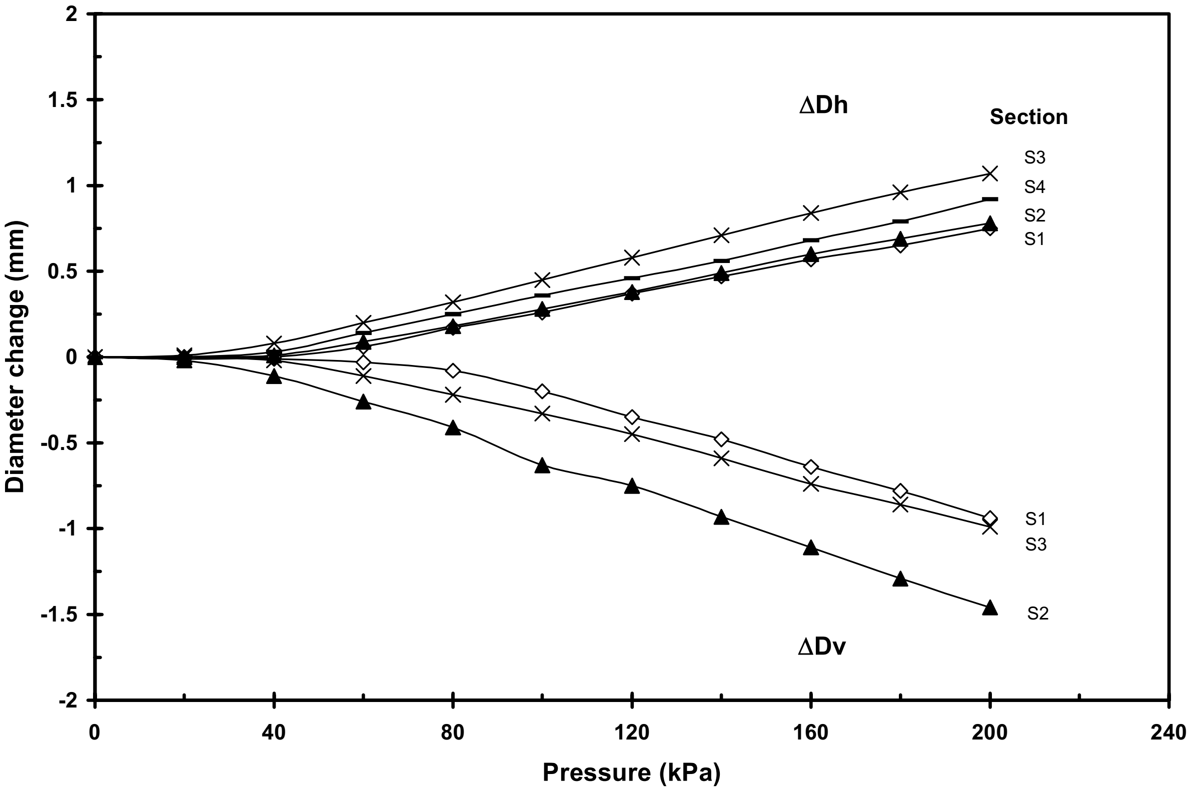


Figure 4. Measured vertical and horizontal diameter change from upsize test 4.

200 kPa as shown in Figure 4. These measured deflections for Test 4 are larger than those for Tests 1 and 3, but similar to the results from Test 2. The deflections for Test 4 and Test 2 start to increase at a similar pressure between 20 and 40 kPa.

Overall, pipe deflections are small with a maximum decrease in vertical pipe diameter, ΔDv, corresponding to less than 1% and an average ΔDv of roughly 0.5% of the pipe diameter at 200 kPa. Although there are no specific guidelines for limiting the deflection of a pipe installed via pipe bursting, for reference ASTM F714 limits the pipe deflection to 4% of the pipe diameter for the particular thickness of pipe tested.

The density of the sand surrounding the HDPE pipe and clay fragment following bursting is unknown and is difficult to quantify. Once the HDPE pipe has filled the expanded cavity, the remaining gap is replaced with loose sand which ravels around the pipe during the bursting process. This phenomenon may partially explain why diameter change in HDPE pipe does not occur on the initial application of vertical pressure, since compression of the sand occurs at the onset of vertical pressure. Inconsistencies in local soil densities around the HDPE pipe could partly explain the delay in measured diameter change, however orientation of broken clay fragments discussed in the next section is more likely the most significant cause.

3.2 Broken clay pipe

Observations made during and following the experiments are now considered to examine the influence of the remnant clay pipe fragments on the new HDPE pipe response.

First, during replacement Tests 1 to 3, cracking sounds originated from inside the test apparatus could be heard once the vertical pressure was applied. It is believed that these sounds were produced by movements along contacts between clay fragments. The cracking sounds were more pronounced during the initial 5 minutes of each load increment between 0 and 100 kPa. After 100 kPa, the cracking sounds were noticeably less, but still heard periodically. When the vertical pressures reached 180 kPa, no sounds were heard during any replacement tests. It was interesting that upsize Test 4 produced no audible cracking sounds at any load increment.
Second, upon completion of each test the soil was exhumed down to the pipe level to permit a detailed study of the nature of the broken clay pipe. Air pressure was used to reveal the position of the broken clay fragments without disturbing their orientation relative to the HDPE pipe. Photographs taken following excavation showing the broken clay fragments of replacement Tests 2 and 3 are presented in Figures 5 and 6, respectively.

The fracture pattern observed in Test 3 is similar to that observed for Test 1. For Tests 1 and 3 the broken clay fragments were in contact with each other at many locations along the pipe, as shown in Figure 6. Several locations where the gaps between clay fragments were filled with sand were also observed. It is hypothesized that at low applied pressures the clay fragments in contact are able to sustain some load; thus the load acting on the HDPE pipe is small and there is little deflection of the HDPE pipe. As applied vertical loading increases the clay fragments begin to move relative to each other, allowing transfer of load to the HDPE pipe. It is believed that variations in measured deflections arise from the variable contact conditions between fragments.

The fracture pattern observed in Test 2 (Figure 5) differs from that observed in Tests 1 and 3. A pronounced crack (approximately 890 mm long and 30-35 mm thick) was observed along the crown of the clay pipe that was filled with sand, preventing direct contact between the clay fragments above the HDPE pipe. It is further hypothesized that the reduced contact between the broken clay fragments leads to greater loads reaching the pipe (relative to Tests 1 and 3) and hence larger pipe deflections. The reduced contact between fragments likely also explains the shorter offset in deflections for Test 2 relative to 1 and 3.

Figure 5. Photograph showing broken clay fragments from Test 2.

A photograph of the broken clay pipe fragments for upsize Test 4 is shown in Figure 7. The broken clay fragments produce different fracture patterns than those seen with the replacement tests. Unlike the replacement test, the clay pipe fragments do not encase the HDPE pipe or provide additional hoop strength. The smaller clay pipe was broken into much smaller fragments, and displaced radially around the new HDPE pipe, suggesting that the clay pipe has not provided any additional hoop strength. No sounds were heard during any vertical pressure increase, reconfirming that no interaction of clay fragments occurred. When no interaction of the clay fragments occur, the delay in measured diameter change appears to be arise from expansion and subsequent contraction of the soil cavity around the pipe during he pipe bursting process. Diameter change at low vertical pressure is not detected since compression of the soil locally around the HDPE pipe occurs. This phenomenon was also seen in Test 2 which explains the delay in measured diameter change where clay fragments surrounded the HDPE pipe but were not in contact with each other.

Figure 6. Photograph showing broken clay fragments from Test 3.

4. CONCLUSIONS

Measurements of vertical and horizontal diameter change were reported for an HDPE pipe installed using pipe bursting methods and subject to increases in vertical pressure. Visual observations and measured diameter changes showed how interactions between the remnant fragments of the original clay pipe can influence the response of the new HDPE pipe. In two replacement tests, the pipe deflection was smaller than expected most likely because of additional support provided by the remnant fragments, whereas in another case, for otherwise identical conditions, much larger pipe deflections were measured. An upsize test showed similar results to one of the replacement tests where little additional support was provided by surrounding broken clay fragments. Although large variations in pipe deflections were measured for both the replacement and upsize tests, the measured diameter change was small (a maximum diameter change of less than 1%, and an average change less than 0.5% of the original pipe diameter).

In addition to the stiffness of the new pipe and backfill soil, the deflections of the new HDPE pipe also appear to depend on cavity expansion and contraction of the soil surrounding the pipe from the pipe bursting process and interactions between remnant clay fragments. The first is difficult to quantify since the soil follows a complex loading path as the burst head initially expands the cavity (to allow the new pipe to be pulled in place) followed by subsequent contraction (since the new HDPE pipe is slightly smaller than the burst head), and then further contraction as additional vertical pressure is applied. This may result in a delay in deflection of the new pipe. The second is also difficult to quantify given the highly variable size, shape and location of the broken clay pipe fragments. Visual observations during pipe exhumation showed that when clay pipe fragments were in contact with other fragments, smaller values of pipe deflection and an increased delay in HDPE pipe response were measured, which is consistent with shielding of the new pipe by clay fragments.

Figure 7. Photograph showing broken clay fragments from Test 4.

5. ACKNOWLEDGEMENTS

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