Self-diagnostic PVC pipes for capturing threats in underground water pipelines

Vinh Q.C. Tran[1][0000-0002-8817-4528] , Duc V. Le[2][0000-0001-7851-0869],

Doekle R. Yntema[3][0000-0002-4432-6577], and Paul J.M. Havinga[4] [0000-0002-3399-1790]

[1,2,3,5] University of Twente, Drienerlolaan 5, 7522 NB, Enschede, The Netherlands
[1] q.c.v.tran@utwente.nl
[2]v.d.le@utwente.nl
[4]p.j.m.havinga@utwente.nl

[1,3] Wetsus, Oostergoweg 9, 8911 MA, Leeuwarden, The Netherlands
[4]doekle.yntema@wetsus.nl

Abstract.
A premature crack and pipe bending are two of the major signals indicating future failures of a PVC water main. Identifying these defectives when they are young can prevent the break consequence. A new PVC pipe concept that can diagnose its premature crack based on changes in pressure strain characteristics has been introduced. However, the bending influence has yet to be fully explored in this pipe concept. Therefore, this research investigates the full impacts of both bending and a premature crack on the pressure strain characteristic. The result reveals different patterns of pressure strain characteristic deviation between bending and a premature crack. It can help future research to design a method to detect and discriminate these pipe defectives.

Keywords: Pressure strain characteristic, Premature crack, Pipe bending.

1 Introduction

A PVC water pipe failure often occurs in a huge crack, which leads to severe consequences [4]. Defective pipes must be addressed and replaced in time to prevent pipe failures. A premature crack and bending in a PVC pipe are the early warning signals for the pipe's upcoming failures [1]. They need to be identified as soon as possible so that the defective pipe can be replaced before the failure.

A self-diagnostic PVC water pipe that can detect a premature crack, as in Fig. 1, has been introduced in [2]. The conduit with attached strain gauges and a local processing device regularly senses and analyses its state to realise a young crack quickly. They are protected by a cover layer and can be installed as conventional water pipes in the field.

In [2], the author revealed that a premature crack changes the pressure strain characteristic (PSC) around it. This change is a prospective signal for early crack detection. In addition to the crack, the temperature and pipe bending were also investigated. For the pipe bending, the authors stated that it significantly affects the PSC. They estimated the bending effect by applying the bending stress to the relation between the external stress and the PSC. However, the external stress in such relation is external hoop stress.

It does not represent the bending, of which the stress is distributed in the axial direction [5]. Therefore, this study investigates the impact on PSC of a real PVC pipe bending and compares it with other effects from a premature crack and temperature. Furthermore, we also reveal the pattern of each factor on the PSC deviations. These patterns can help to develop a method to detect and discriminate the crack and bending.

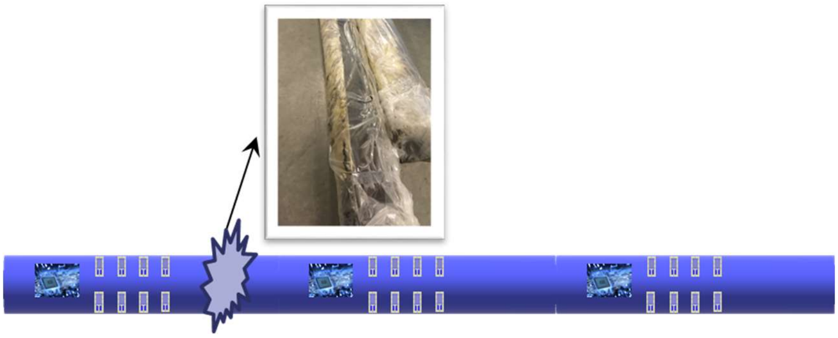

Fig. 1. Self-diagnostic PVC pipes

2 Methodology

We apply the same methodology used in [2] to explore the cracks, bending and temperature impacts on the pressure strain characteristics (PSC). The PSC is the relation between the internal pressure and the hoop strain on the pipe wall. In normal operation of a drinking water system, the pressure varies from 1-5 bars depending on the consumption during the day [7]. In this range, the PSC is linear as in Fig. 2 [6]. An existence of crack or bending, or temperature makes the PSC at adjacent area shifted from their original lines.

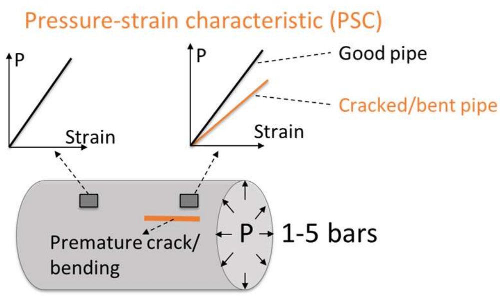

Fig. 2. Influence of a premature crack and bending on the pressure strain characteristic

To build the distributed PSC, we need static pressure at various points between 1 to 5 bar and the corresponding hoop strain at the desired locations. Then, we applied linear regression on the pressure and strain data to construct the PSC for each location [2].

3 Experiments

We set up the experiment based on the recommendation of [2] as in Fig. 3. We used a 1-meter long section of a 63mm diameter, 2.3mm thickness of PVC water pipe and sealed its heads. Furthermore, we controlled the pipe temperature by filling it with water at temperature values: 25°C, 19°C and 15°C. The pipe was connected to a manual pump to induce static water pressure for constructing the PSC.

To make the pipe bend, we fixed its two terminals and adjusted the height of a movable beam in the middle. We tested with four bending rates: 0.5°, 1°, 3°, and 6°. On each side of the adjustable beam, we attached 12 strain gauges divided into three rows at 12, 3 and 6 o'clock locations in the circumferential direction. Each row consists of 4 strain gauges at a distance of 100mm space. Each strain gauge was connected to an HX7111 analogue-to-digital converter, and an Arduino board collected data from all the HX7111s.

For the crack, we used a razor to make 100mm cracks with depths of 1/3 and 2/3 of the pipe wall thickness, which were respectively named shallow and deep cracks.

At each pipe and temperature condition, we varied the pressure by at least four points in the range of 0 to 5 bars and collected the pressure and strain data. Then we constructed the PSC of each strain gauge location from these data. Finally, we investigate the deviations of these PSCs to their original values of the good pipe at 25oC to figure out their patterns.

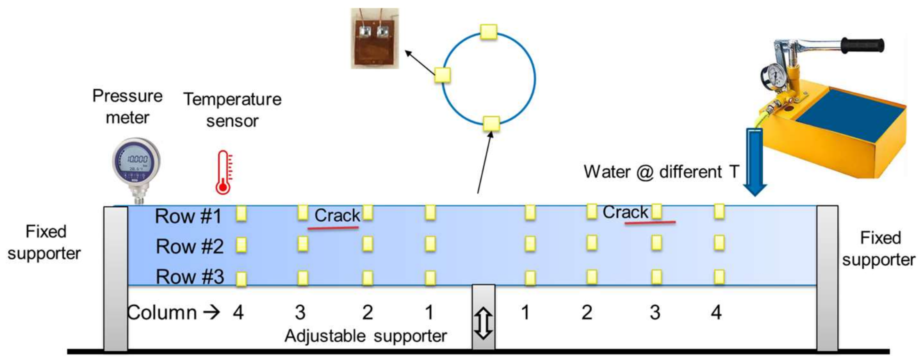

Fig. 3. Testbed for investigating the impact of bending, crack and temperature of the PSC. Two setups of three rows and four columns of strain gauges are at two sides of the bending beam.

4 Result

Figure 4 illustrates the influences of bending, cracks and temperature on the PSCs on the right side of the adjustable beam in Fig.3. In these figures, the changes are the PSC deviations from their good state at 25°C ones. We can see different patterns of the PSC deviation appropriated to each impact.

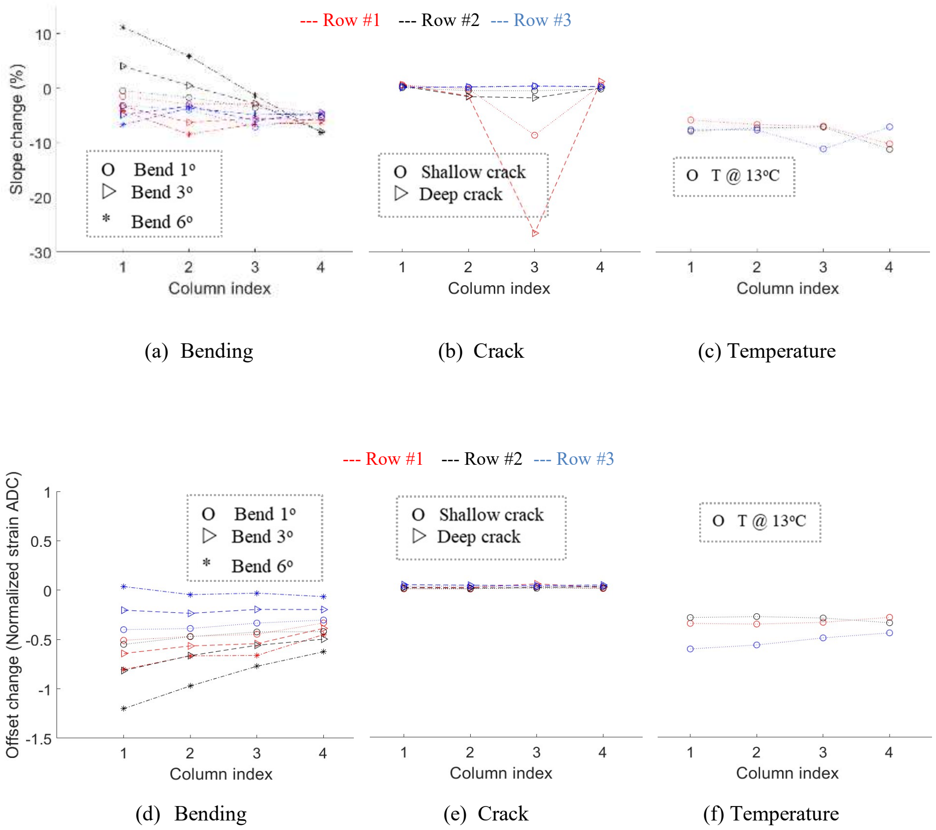

Fig. 4. Changes of PSC caused by different types of bending, crack and temperature measured by the strain gauges on the right side of the adjustable beam in Fig. 3. The colours and X-axis index, respectively, correspond to the rows and columns of strain gauges in Fig.3

For the bending, as in Fig. 4a and 4d, it changes both slopes and offsets of all locations. Its pattern follows the pipe's axial deformation. The more bending and the closer the locations to the beam are, the larger their PSCs deviate. Furthermore, the higher magnitudes of the row #2 pattern compared to the ones of rows #1 and #3 can reveal the bending direction.

Regarding the crack in Fig. 4b and 4e, only the slope magnitude of the adjacent location is significantly decreased. The slope's dropping rate is appropriated to the crack depth. Finally, the temperature, as in Fig. 4c and 4f, affects both the slope and offset at all locations but has a different pattern from the bending ones. The temperature pattern is mostly similar at all sites. The different variations between locations may come from the variant sensitivity of each strain gauge as well as the bonding of each strain gauge to the pipe wall.

5 Conclusion

This paper studies the impacts on the pressure strain characteristic (PSC) of bending, a premature crack and temperature. Three different patterns of PSC deviation corresponding to these three factors are revealed. While the crack only influences the PSC slope of its adjacent area, bending and temperature affect both the slope and offset at all the locations. However, the PSC deviation magnitude of the bending is proportional to its distance to the bending centre, whereas the temperature ones are mostly flattened. These patterns can be helpful for future research to detect and discriminate a premature crack and bending to the temperature.

Last but not least, though the PSC offset pattern relates to the type of the three impacts, applying it to discriminate these factors must consider the effect of soil compression, which significantly contributes to the offset as in [2]. The arbitrary variation of soil compression in time and space can decrease the performance of the model using the PSC offset.

References

1. V. Q. C. Tran, D. V. Le, D. R. Yntema and P. J. M. Havinga, "A Review of Inspection Methods for Continuously Monitoring PVC Drinking Water Mains," in IEEE Internet of Things Journal, vol. 9, no. 16, pp. 14336-14354.
2. V. Q. C. Tran, D. V. Le, D. R. Yntema and P. J. M. Havinga, "Data underlying the publication: Testbed Hardware Design to Collect Data for Underground PVC Water Pipe Crack Detection: Challenges and Solutions.", 4TU.ResearchData. Dataset. https://doi.org/10.4121/21340608.v1
3. Tarek M. A. A. EL-Bagory and Maher Y. A. Younan. 2016. Crack Growth Behavior of Pipes Made From Polyvinyl Chloride Pipe Material1. Journal of Pressure Vessel Technology 139, 1 (08 2016)
4. Yasuhiro Arai, Akira Koizumi, Toyono Inakazu, Haruhiko Watanabe, and Masahiro Fujiwara. 2010. Study on failure rate analysis for water distribution pipelines. Journal of Water Supply: Research and Technology—AQUA 59, 6-7 (2010).
5. Yahong Ding, Heng Yang, Ping Xu, Minxia Zhang, and Zhenguo Hou. 2021. Coupling Interaction of Surrounding Soil-Buried Pipeline and Additional Stress in Subsidence Soil. Geofluids 2021 (2021), 16.
6. F Povolo, G Schwartz, and Élida B Hermida. 1996. Stress relaxation of PVC below the yield point. Journal of Polymer Science Part B: Polymer Physics 34, 7 (1996), 1257–1267.
7. Vewin, 2017. "Dutch drinking water statistics 2017: From source to tap. ", https://www.vewin.nl/SiteCollectionDocuments/Publicaties/Cijfers/Vewin-Dutch-Drinking-Water-Statistics-2022-ENG-WEB.pdf. Last access on 2022/15/11.