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Evaluation of bending behavior of flexible pipe using digital image processing

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Abstract

The pipe-in-pipe proposed by the authors in this study, consists of an inner and an outer pipe. The core between the inner and outer pipes is filled with a granular material. The pipe-in-pipe can bend smoothly and uniformly under large curvature in comparison with the single walled pipe. In recent years, digital image processing as a method for measuring deformation of structures has been widely adopted. In this study, the authors show the effect of fill sand on the bending behavior of a single walled pipe, and evaluate the elasto-plastic behavior of the pipe by using digital image processing method.

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Keywords: pipe-in-pipe; Brazier Effect; granular material; digital image processing; elasto-plastic behavior

1. Introduction

When pipeline is buried underground, it may be subjected to severe bending deformation due to landslides, uneven frost heaving or earthquakes [1]. One of the typical failures of a pipe subjected to bending moment is local buckling which is known as the Brazier effect [2]. Improving material strength of the pipeline is one of the possible solutions. However, this solution cannot withstand large residual displacement, and the construction cost becomes expensive. On the contrary, flexible and ductile pipe with common materials is an alternative and inexpensive solution. Therefore, the authors are working on the development of a pipe-in-pipe which can bend smoothly and flexibly under large curvature [3].

Fig. 1 shows the pipe-in-pipe which is proposed in this study. This structure consists of concentric thin walled pipes, with granular material such as sand filling the core between the outer and the inner pipes, in order to transmit

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interactive stress within a cross section. If a single walled hollow pipe is subjected to bending moment, the curvature of the pipe increases with an increase in bending moment. By increasing the bending moment further, the pipe eventually fails locally with an oval shaped deformation in cross section as shown in Fig. 2.

In order to adopt such a pipe-in-pipe as a practical pipeline material, it is necessary to evaluate the elasto-plastic behavior of the pipe. Furthermore, in order to evaluate the elasto-plastic behavior of the pipe, it is necessary to carry out experiments with reliable and accurate observation of bending. The strain gauge is widely used for measurement of strain because of its cost and accuracy. The authors have actually used strain gauges to this point to observe the bending behavior of pipe, attaching strain gauges at the center of the loading span. However, pipe-in-pipe filled with frozen sand can bend much more than expected, and the maximum strain exceeds the limits of strain gauge. The authors decided to introduce a digital image processing technique as a measuring method of bending behavior, instead of the conventional strain gauge. This method of digital image processing records pictures of the pipe during the experiment using a high-resolution camera. The deformation of the pipe is calculated by multiplying the location change between pictures (by pixel count) by a conversion constant relating pixels to millimeters. When strain gauges are used for measurement, the number of measuring points along the pipe is limited, and we can know the curvature only at the points where strain gages are attached. Consequently, it is almost impossible for us to evaluate the continuous deformation of the pipe between the loading points. On the other hand, in digital image processing, it becomes possible to follow the overall deformation of the pipe just by increasing the number of calculation points along the longitudinal direction, with an interpolation function for deformation. This digital image processing method is described later in detail.

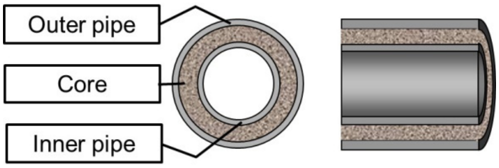

Fig. 1. Pipe-in-pipe

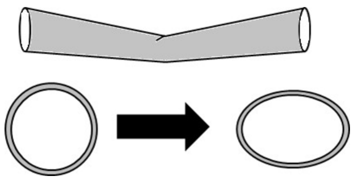

Fig. 2. Brazier Effect

2. Experimental method

2.1. Testing apparatus

The testing apparatus is illustrated in Fig. 3. The pipe is supported at both ends, and two loading points are located near the center of the span. The distance between the two loading points is 520 mm. The bending moment between the two loading points is constant, and its magnitude is proportional to the load. Since a load-cell is placed between the loading device and the actuator, the loading magnitude can be easily converted into bending moment. The loading magnitude is gradually increased over time, so that the effect of dynamic motion is negligible. A high-resolution camera, Canon EOS 40D, records a picture every 10 seconds while loading. The loading stops when the pipe is broken, or the loading magnitude shows a peak value. The camera was installed as shown in Fig. 4. The resolution of each picture recorded by the camera is 3,888 by 2,592 pixels, totaling about 10.10 effective megapixels.