DEFORMATION ANALYSIS OF PIPELINE WITH LASER DISPLACEMENT METER AND 3D CAMERA

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***ABSTRACT*:** This paper gives the new methods to investigate the pipeline. One is the method using the 3 D camera and another is the one using the laser displacement meter. For the method using the 3D camera, the configuration of the pipe is measured by examining the location of the spots from the laser pointer. The second method is using the 1D laser displacement meter. By rotating the 1D laser displacement meter with stepping motor, the configuration of the pipe is measured. Both methods are very simple and economic. It is expected to reduce the accident of the pipelines by monitoring the deformation of the pipe with the methods developed in this study

KEYWORDS: Pipeline, 3D camera, Deformation monitoring

1. INTRODUCTION

While the pipelines are used as aquatic system, the maintenance is very difficult. This is because the pipeline systems are constructed under the ground and the monitoring is difficult. As the present measurement method, the 3D laser scanner is tried to monitor the configuration of the pipe. However, the monitoring is actually difficult because of the high cost. The configuration is also measured by handling the gauge. However, this is very labored, and so the monitoring is not actually carried out (Kinki Regional Agricultural Administration Office, 2011). Therefore, the sudden accident such as breaking has occurred when water was delivered. Fig.1 shows a situation of the breaking of the pipeline. In the case of such a breaking, the upper construction is broken and water distribution is cut off. Before breaking, the pipe has some cracks or is deformed in many cases. Fig.2 shows the inner situation of pipe, in which the deformation can be seen. As the asset management,

Fig.1 Breaking situation of pipeline

Fig.2 Inner situation of deformed pipe

the deformation or damage leading to the breaking has to be cared.

To examine the condition of pipelines, the inner situation has to be investigated when water is not delivered. The monitoring method has to be simple because the pipeline is very long and the investigation period is short. In this study, the new methods to investigate the pipeline are developed. One is the method using the 3 dimensional (3D) camera and another is the one using the laser displacement meter. For the method using the 3D camera, the calibration is firstly carried out to obtain the camera parameters. The configuration of the pipe is measured by examining the location of the spots from the laser pointer. The spots are moved as helical shape on the inner surface of the pipe. By this method, the deformation of the pipe can be examined. The second method is using the laser displacement meter. Instead of the expensive 3D laser scanner, 1D laser scanner is applied in this study. The 1D laser scanner can measure the distance from the reflection of the laser beam. By rotating the 1D laser displacement meter with stepping motor, the configuration of the pipe is measured. Both methods are very simple and economic. It is expected to reduce the accident of the pipelines by monitoring the deformation of the pipe with the methods developed in this study.

2. METHOD USING 3D CAMERA

2.1 Basic theory

Firstly, the parameters to connect the actual coordinate (X,Y,Z) with the pixcel (X_c, Y_c) have to be identified. The following equation is the basic relation of both coordinates (CG-ARTS Association, 2004).

$$\begin{bmatrix} H_c X_c \\ H_c Y_c \\ H_c \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ C_{21} & C_{22} & C_{23} & C_{24} \\ C_{31} & C_{32} & C_{33} & C_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{1}$$

H_c is the scale parameter, C_{ij} is the camera parameters. By setting C_{34}=1 and eliminating H_c, the following is obtained.

$$\begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -Y_1X_{c1} & -Y_1X_{c1} & -Z_1X_{c1} \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -X_1Y_{c1} & -Y_1Y_{c1} & -Z_1Y_{c1} \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{12} \\ C_{13} \\ C_{14} \\ C_{21} \\ C_{22} \\ C_{23} \\ C_{24} \\ C_{31} \\ C_{32} \\ C_{33} \end{bmatrix} = \begin{bmatrix} X_c \\ Y_c \end{bmatrix} \tag{2}$$

This equation is obtained for a single actual location of (X_1, Y_1, Z_1) and its coordinate on the picture, i.e., (X_{c1}, Y_{c1}). As the number of camera parameters is 11, if the points of which number is larger than 11 are observed, the parameters can be identified. The equation can be written as

$$\mathbf{AC}=\mathbf{R} \tag{3}$$

Where **A** is the coefficient matrix, **C** is the vector of camera parameters and **R** is the vector of coordinate on the picture. **C** vector is obtained by the least square method as

$$\mathbf{C}=(\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{R} \tag{4}$$

Then, by using two cameras of which the camera parameters are identified, the 3D coordinates of a point can be obtained. As shown in Fig. 3, the coordinate on the pictures for the same point is obtained by two cameras as (X_L, Y_L) and (X_R, Y_R). Then, by solving the following equations (5), the coordinate of a point (X,Y,Z) can be obtained.

$$\begin{aligned} &(C_{11}-C_{31}X_R)^{(R)}X+(C_{12}-C_{32}X_R)^{(R)}Y+(C_{13}-C_{33}X_R)^{(R)}Z=C_{34}X_R-C_{14}{}^{(R)} \\ &(C_{21}-C_{31}Y_R)^{(R)}X+(C_{22}-C_{32}Y_R)^{(R)}Y+(C_{23}-C_{33}Y_R)^{(R)}Z=C_{34}Y_R-C_{24}{}^{(R)} \\ &(C_{11}-C_{31}X_L)^{(L)}X+(C_{12}-C_{32}X_L)^{(L)}Y+(C_{13}-C_{33}X_L)^{(L)}Z=C_{34}X_L-C_{14}{}^{(L)} \\ &(C_{21}-C_{31}Y_L)^{(L)}X+(C_{22}-C_{32}Y_L)^{(L)}Y+(C_{23}-C_{33}Y_L)^{(L)}Z=C_{34}Y_L-C_{24}{}^{(L)} \end{aligned} \tag{5}$$

Fig. 4 shows the cube used for the calibration of camera parameters. The length of a side is 15 cm. In this study, to examine the effect of the largeness of the image for the calibration, the distance to the cube is set at 30 cm, 60 cm and 90 cm.

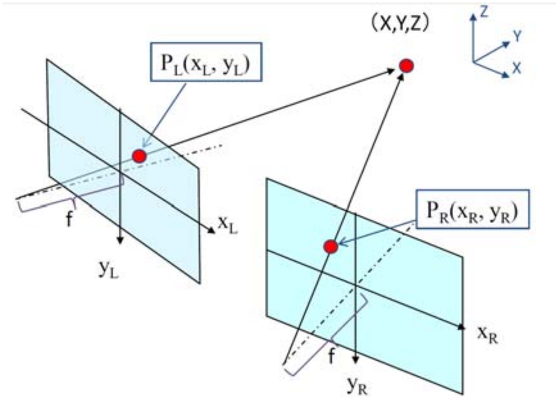

Fig. 3 Lines of sight for the same point

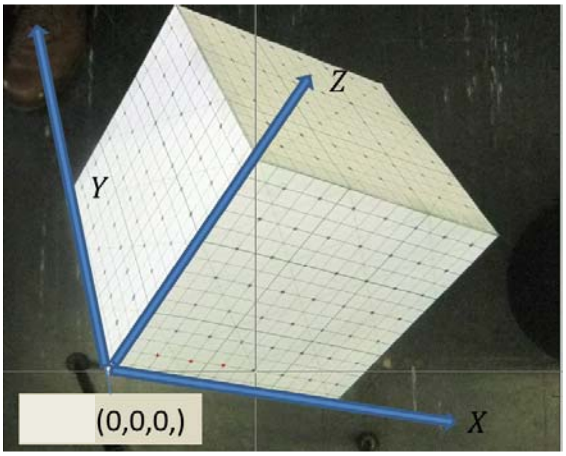

Fig.4 Cube for calibration of camera parameters

2.2 Results

Fig. 5 shows the experimental situation. The pipe is made with heavy paper. The length is 79 cm and the maximum diameter is 35cm. The circumference is changed from 109 cm at the upper entrance to 99 cm at the lowest part on the floor. The camera is FINEPIX REAL 3D by FUJIFILIM, of which number of pixel is 2048 × 1536. Fig.6 indicates the locus of spots illuminated by the laser pointer. The location of the spot is measured on the helical shape in the pipe. The distance between the spots is about 7 cm. The 3D location of the spot is calculated with the basic theory mentioned above. However, the direction of the camera cannot be set correctly at the depth direction of the pipe. The coordinate is corrected with the information of the depth direction of the pipe, which is measured separately. The shape of the pipe at three distance from the upper entrance (20, 40 and 60 cm) is estimated with the corrected coordinates on a spiral of which central depth is located at the distance.

The estimated shapes at three different depths from the upper entrance are shown in Figs. 7 to 9. The shape is obtained with the different calibration distance (30, 60 and 90 cm). The center of the circle is dependent on the location of the camera, which does not necessarily correspond to the center of the pipe, although the direction is corrected with the above mentioned method.

Fig. 5 Experimental situation

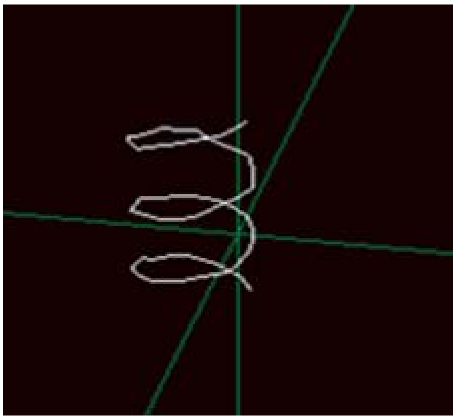

Fig.6 Locus of laser pointer

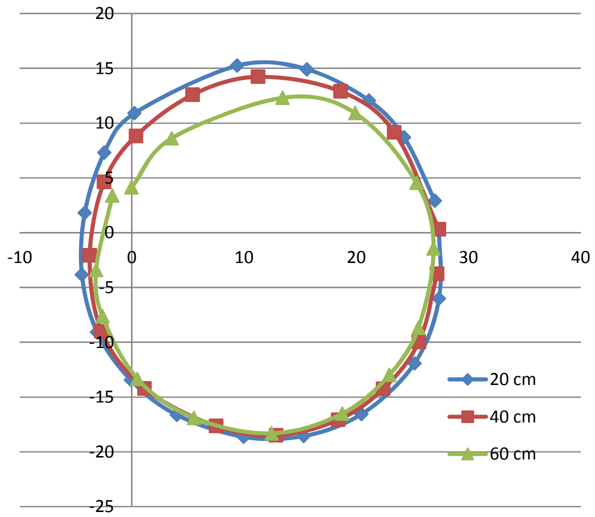

Fig.7 Measured shape (Calibration distance of 30 cm)

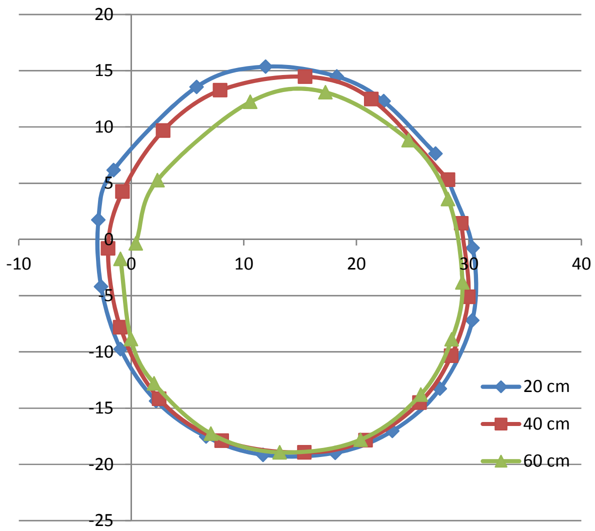

Fig. 8 Measured shape (Calibration distance of 60 cm)

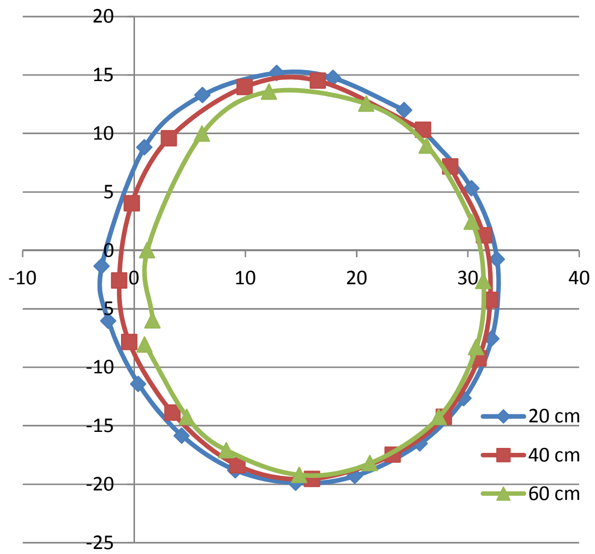

Fig. 9 Measured shape (Calibration distance of 90 cm)

Table 1 Error of diameter

(unit: cm, C.D.: Calibration Distance)

Location	20 cm	40 cm	60 cm	Average
30cm C.D.	0.27	0.54	1.02	0.61
60cm C.D.	0.14	0.10	0.56	0.26
90cm C.D.	0.64	0.36	0.13	0.37

While the results with the different calibration distance are mostly similar as shown in Figs. 7 to 9, the error is calculated as shown in Table 1. The shape obtained with camera parameters calibrated with the distance of 60 cm shows the smallest error. The distance at the center of the pipe from the camera location is mostly the same as the calibration distance. It can be concluded from the above results that the calibration of camera parameters has to be carried out with the different distances. Then, the location measured at the site is examined with the camera parameters calibrated with the mostly same distance.

3. METHOD USING LASER DISPLACEMENT METER

3.1 Mechanical elements

We try to make another machine to measure the figure of pipe with the 1D laser displacement meter. While 3D laser displacement meter is very expensive, 1D meter is relatively cheap. CMOS Laser sensor IL-600 by KEYENCE (KEYENCE, 2012) is used in this study, which can measure the distance between radiation port and irradiated point. The accuracy is 0.1 mm and the measureable distance is from 200 mm to 1000 mm.

To measure the figure of the pipe, the internal radius is measured by rotating the laser displacement sensor with a given angle in a pipe. For rotation, the stepping motor is used. Fig. 10 shows the assembled machine. By rotating the 1D laser displacement sensor with interval angle of 9°, the shape of the pipe is measured at 40 points. The laser displacement sensor is fixed with the angle of 30° to the stepping motor. The figure of pipe ahead of the sensor can be monitored as shown in Fig. 11. The inner radius of a pipe can be calculated from the configuration of the assembled machine shown in Fig. 12. The inner radius R (cm) can be obtained from the following equation with the distance measured by the laser displacement sensor, D (cm).

$$R = (D+8)\cos 30^\circ + 5.0 \text{ (cm)} \tag{6}$$

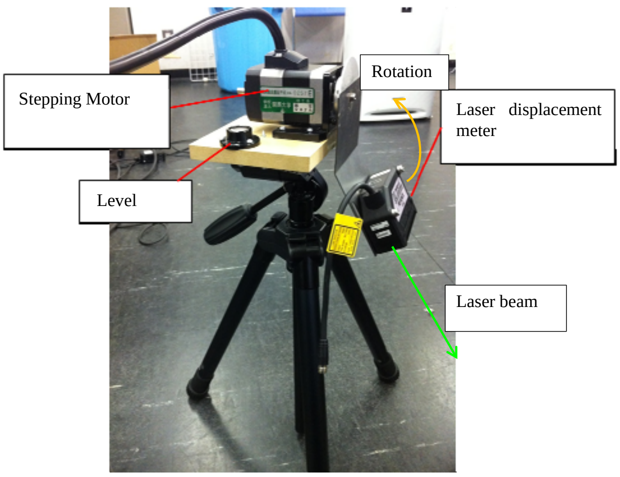

Fig. 10 Assembled machine

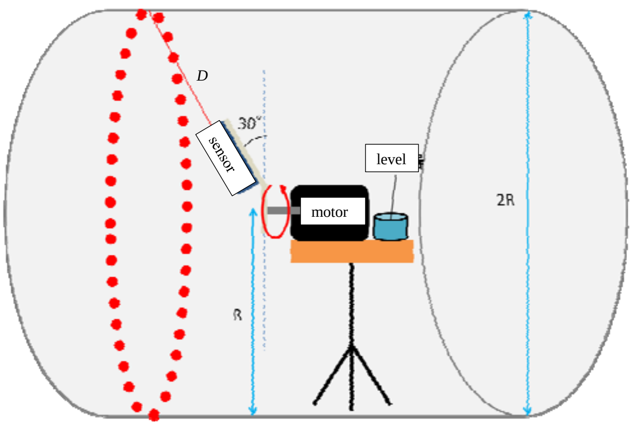

Fig.11 Situation of measurement

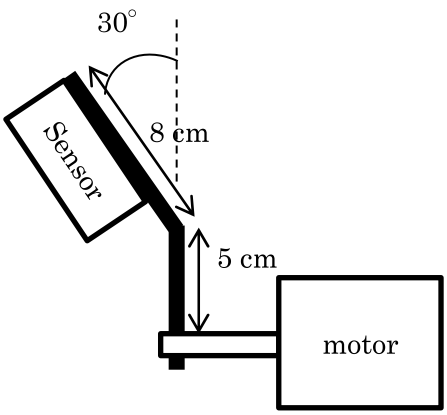

Fig. 12 Detailed size around sensor

3.2 Measurement examples

By using the newly developed machine, the inner figure of a pipe is measured. Fig. 13 shows the configuration of the pipe and the number means the sections measured by the developed machine. The area including from No. 1 to 7 is horizontal, and the area of No. 8 and 9 is declined.

Fig. 14 shows the measured results of the sections from No.1 to 7. The sections show the deformation in the vertical direction and the mostly same figure in the horizontal area.

Then, the inclined sections, No. 8 and 9, are measured. In this case, although the figure at the vertical section is not measured, the inclined section, BC, is measured as shown in Fig. 15.

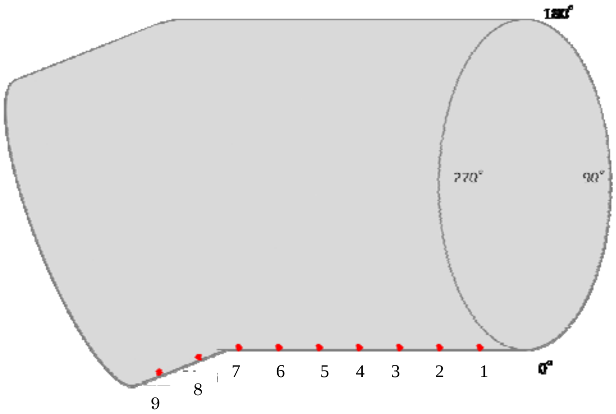

Fig. 13 Pipe configuration

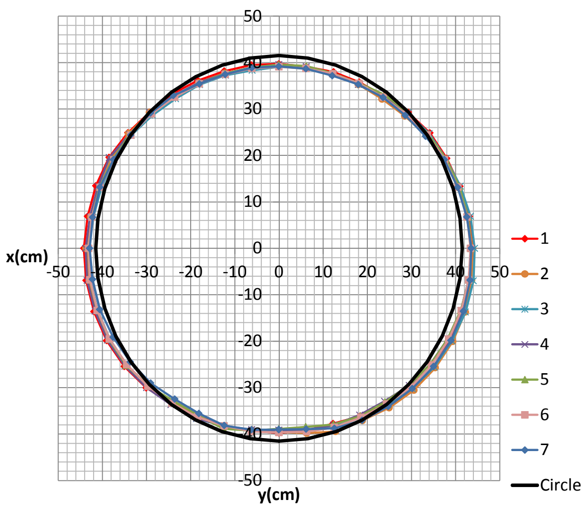

Fig. 14 Measured results from No.1 to 7

By using the configuration shown in Fig. 15, the declined angle α can be measured. Firstly, the length X shown in Fig.15 is calculated with the lengths of AB and AC and the angle ∠BAC (120°) by cosine law. The lengths of AB and AC are obtained from the measurement. Then, the angle, β, is calculated by using the lengths of three sides. While the angle between 0° and 180° is described in Fig. 15, the inclination of the diameter line in all direction can be obtained.

Fig.16 shows the inclination angle of α in all direction. The inclination angle at No.9 in vertical direction is about 9°.

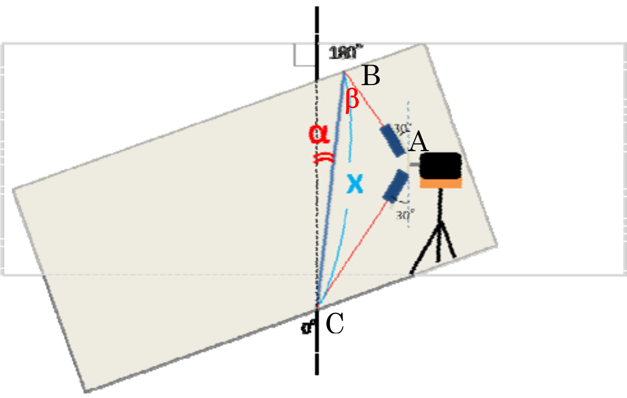

Fig. 15 Inclination angle

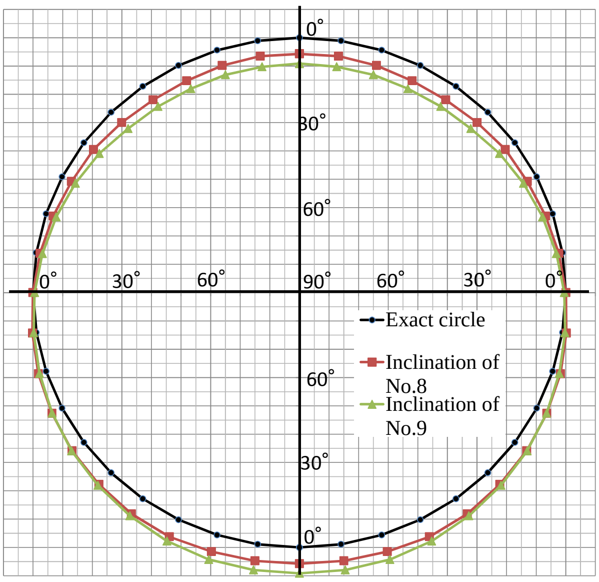

Fig. 16 Measured inclination angles

4. CONCLUSIONS

In this paper, the methods to measure the configuration of pipe line are newly developed. At present, the situation of the pipe has not been examined and so the sudden accident has occurred. While the regular examination is desirable, the examination method has to be simple because the period for the examination is limited in general. The developed method in this paper is very simple and economic, and so it is expected to carry out effectively the examination of the pipeline in a short time by using the newly developed method. The newly developed method is summarized as followings;

1) Taking picture of the spot by laser pointer, three dimensional coordinate of the spot can be measured. The configuration of the pipe can be measured very easily. For the actual usage, it is encouraged that the calibration of camera parameters has to be carried out with the different distances. Then, the location measured at the site is examined with the camera parameters calibrated with the mostly same distance.

2) The configuration of the pipe is measured by the 1D laser displacement meter. The accuracy is better than the above method with 3D camera. The inclination angle is also measured by the method.

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