Reports on Geodesy and Geoinformatics, 2023, Vol. 116, pp. 69–76

DOI: 10.2478/rgg-2023-0012
Received: 15 September 2023 / Accepted: 12 December 2023
Published online: 29 December 2023

ORIGINAL ARTICLE

Solution of inclinometer data processing for horizontal displacement: A case study of basement diaphragm wall monitoring in Vietnam

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Abstract

In the recent decade, Digitilt DataMate II and GK-604D inclinometer systems have commonly been used to evaluate horizontal displacement as well as to test the calculation models of basement diaphragm walls in Vietnam. The difference in the equipment constants as well as the calculation principle has confused the surveyors and even led to erroneous monitoring results. Furthermore, the use of commercial programs DigiPro2 and SiteMater, which are expensive, in inclinometer data processing requires a thorough understanding. Differences in calculation results between software occur due to the choice of the instrument constant, the rounding principle, or the choice of the reference point at the bottom of the monitoring pipe. In this paper, we summarize the calculation principles of Digitilt DataMate II and GK-604D inclinometer systems. To respond well to the data processing of inclinometer systems for basement diaphragm walls in Vietnam, we have developed the ICTool program that can efficiently calculate the observed data of the GK-604D system. The results of inclinometer data processing by the ICTool program are homogeneous in comparison with DigiPro2 and SiteMater software. In addition, the ICTool program was established to provide, free of charge, the communication of the monitoring of basement diaphragm wall displacement in Vietnam.

Key words: inclinometer data processing, DataMate II, GK-604D, basement diaphragm wall, inclinometer instrument constants

1 Introduction

In the world, inclinometer systems are often used for the assessment of landslides and basement diaphragm wall monitoring (Allil et al., 2021; Grodecki et al., 2018; Nguyen and Luu, 2013; Arroyo et al., 2008; Stark and Choi, 2008; Teparaksa and Teparaksa, 2019; Zhang et al., 2018). In the recent decade in Vietnam, inclinometer systems have also been applied to analyze horizontal displacement and test the diaphragm walls model during the construction of basement excavation (Nguyen and Luu, 2013; Van Tram et al., 2014). It can be seen that the correct calculation of inclinometer monitoring data is necessary.

When processing inclinometer calculation data, there are many factors to keep in mind, such as instrument constant, rotation correction, and reference point correction. Notes have been made regarding rotation correction (ASTM D6230-13, 2013; Mikkelsen, 2003) or the movement reference points (usually the inclinometer toe) for calculating wall deflections (ASTM D6230-13, 2013; Grodecki et al., 2018; Hsiung and Hwang, 2009; Hwang and Wong, 2018; Liu et al., 2011; Pham et al., 2021), but instrument constants are not mentioned. In the study of the error sources of the inclinometer system (Mikkelsen, 2003), Mikkelsen showed the instrument constant as 25000 (Metric probe) or 20000 (English probe). The specification (ASTM D6230-13, 2013) states that the calcula-

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tion depends on the device constant K, which is provided by the manufacturer.

In Vietnam, the commonly used inclinometer systems are Digitilt DataMate II and GK-604D. These systems have different instrument constants. Specifically, the DataMate II instrument (Slope Indicator, 2014) has a factor of 20000 for the English unit and 25000 for the metric unit. Meanwhile, the instrument constant value of the GK-604D Inclinometer is always 20000 (Deep Excavation, 2021). SiteMaster and DigiPro2 (Deep Excavation, 2023; Slope Indicator, 2013) are the respective commercial software to make suitable calculations for the GK-604D and Digitilt DataMate II monitoring systems. When using a software to calculate the observed data from the another manufacturer, it is necessary to choose the suitable instrument constant following the calculation principle. For example, when processing GK-604D data using Geoslope's DigiPro2 software, without any notes from the manufacturers, an instrument constant of 40000 was selected to obtain the correct displacement value according to the calculation principle of Geokon manufacturer. These confusions in the inclinometer data processing have put the Vietnamese surveyors in an embarrassing situation and there is even a possibility that readings are interpreted incorrectly resulting in misleading wall deflections (Moffat et al., 2019).

The paper Dung et al. (2020) presents a study on recommendations for collecting and processing inclinometer data for basement diaphragm walls in Vietnam. In this paper, we clarify the calculation principles for the Digitilt DataMate II and GK-604D devices; the ICTool program was developed to contribute to the GK-604D data processing. Raw data for 9 cycles of an inclinometer belonging to the project at 165 Xa Dan, Hanoi, were used to test the ICTool program in comparison with commercial software DigiPro2 and SiteMaster 2012. The ICTool program is a freely accessible tool that we have developed and generously shared on The Open Science Framework (OSF) website (ICTool, 2023). This program stands as a cost-effective solution to benefit users globally, particularly those who may lack access to costly commercial software. Additionally, it also serves as a valuable alternative for researchers working with inclinometer data, eliminating the need for investment in expensive commercial software. In this regard, the results of this study are of interest to the structural health monitoring community as well as many surveying engineering applications. In addition, they can be instructive from an educational point of view, as well as beneficial to the on-site implementation.

2 Methodology

2.1 General principle of inclinometer monitoring

Inclinometer monitoring is based on the operating principle of the accelerometer sensors located at the probe. When measuring horizontal displacement, the probe has a system of two wheels running along the grooves in the casing. The probe consists of two force-balanced accelerometers: an accelerometer that measures inclination in the plane of the probe wheels, which is called the A axis (commonly referred to as the direction of pressure); the other accelerometer measures the inclination in the plane perpendicular to the plane of the wheels, this plane is called the B-axis, Figure 1.

In Figure 2 (a), the deviation (d_i) at each monitoring position of the casing is the relationship between the angle of inclination (θ_i – determined by the accelerometer) and the reading interval (L) calculated by Eq. (1).

$$d_i = L \sin \theta_i \quad (1)$$

In which: d_i is the deviation, L is the measurement interval (usually 0.5 m or 2 feet), θ_i is the angle of tilt compared to the vertical at the i^{th} measurement point.

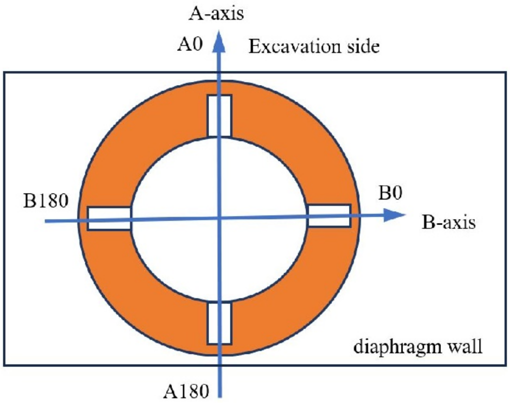


Figure 1. Conventional directions A and B in monitoring Horizontal displacement inclinometer

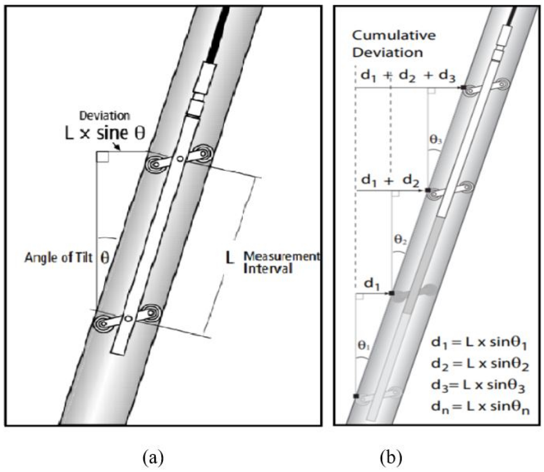


Figure 2. The values of deviation (a) and cumulative deviation (b) (Slope Indicator, 2011)

The cumulative deviation (d) of each axis of the casing is the sum of the lateral deviations (d_i) calculated from the bottom of the casing, Figure 2 (b), shown in Eq. (2).

$$d = d_1 + d_2 + d_3 + \cdots + d_n \quad (2)$$

In which: d is the cumulative deviation from the bottom of the casing, and d_i is the deviation of each measurement interval.

The cumulative deviations of the casing compared to the vertical are used to determine the horizontal displacement value along the depth of the observed object.

DigiPro2 and SiteMaster software are calculation tools provided for data processing of Digitilt DataMate II and GK-604D instruments respectively. The principles of these calculation are detailed in the following paragraphs.

2.2 Calculation principle of Digipro2 software

The readings displayed on the Digitilt DataMate II and imported into Digipro2 software are not the angle or deviation of the casing, Figure 3. These results are proportional to the tilt angle of the casing and the instrument constant, which is represented by the following Eq. (3).

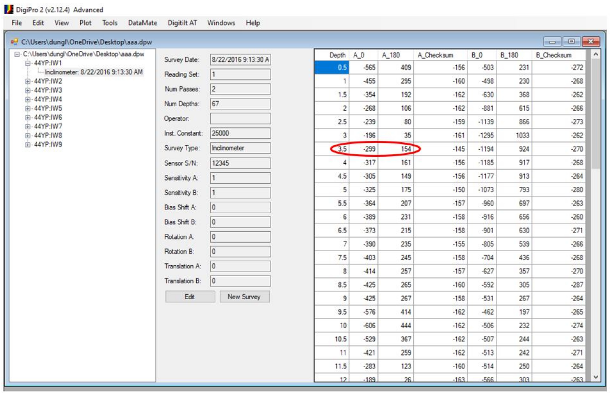
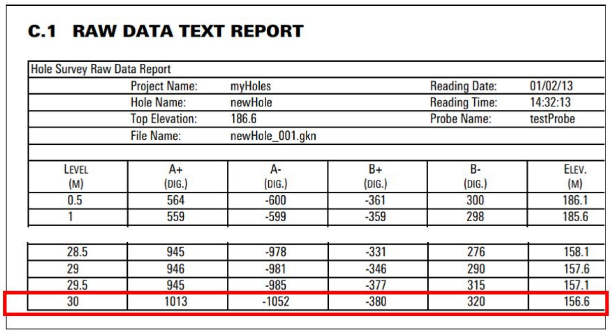


Figure 3. Observed data displayed in Digipro2 software



C.1 RAW DATA TEXT REPORT

Hole Survey Raw Data Report

Project Name:	myHoles	Reading Date:	01/02/13
Hole Name:	newHole	Reading Time:	14:32:13
Top Elevation:	186.6	Probe Name:	testProbe
File Name:	newHole_001.gkn		

LEVEL (M)	A+ (DIG.)	A- (DIG.)	B+ (DIG.)	B- (DIG.)	ELEV. (M)
0.5	564	-600	-361	300	186.1
1	559	-599	-359	298	185.6
28.5	945	-978	-331	276	158.1
29	946	-981	-346	290	157.6
29.5	945	-985	-377	315	157.1
30	1013	-1052	-380	320	156.6

Figure 4. Raw data obtained from GeoKon GK-604D device (Deep Excavation, 2021)

$$D_i = \mathrm{IC} \sin \theta_i \tag{3}$$

In which: D_i is the lateral deviation, and IC is the instrument constant.

In a two-way measurement, the result of lateral deviation is the average value of two reversal measurements, Eq. (4). The first measurement has a conventional 0° direction and the second one is 180° when the probe is reversed. This two-way measurement allows the detection of systematic errors through check-sum value, which is the algebraic sum of the measured values in the two directions 0° and 180° for each reading interva; this value should theoretically be zero.

$$D_i = (A_0 - A_{180})/2 \tag{4}$$

In which: A_0 is observed data in the 0° direction of axis A, and A_{180} is observed data in the 180° direction of axis A.

In two readings, we always have direction A_0 and A_{180} readings with opposite signs. Thus, the relationship between Eq. (1) and the observed data shown in Eqs. (3, 4) give us the value of the horizontal deviation in the depth of the casing in each interval, which is represented by Eq. (5).

$$d_i = L \sin \theta_i = L \left(\frac{D}{\mathrm{IC}}\right) = L (A_0 - A_{180}) / (2\mathrm{IC}) \tag{5}$$

For example, to calculate the red oval in Figure 3 with observed data at a depth of 3.5 m, and according to the calculation instructions of the Digitilt DataMate II device (Slope Indicator, 2011), with the device constant IC = 25000 (in metric units) and the probe length L = 500 mm, we can calculate the lateral deviation of the A axis with reading $A_0 = -299$ and $A_{180} = 154$ which is $d_i = -4.53$ mm in applying Eq. (5).

The horizontal displacement value is calculated by subtracting the initial lateral deviation from the current deviation. Since this value is the horizontal movement of the casing, this value is also the horizontal displacement of the observed object.

2.3 Calculation principle of SiteMaster software

The probe of GK-604D, including two Micro-Electro-Mechanical Sensor accelerometers, directly gives A+, and A- readings at each monitor depth when the wheels of the probe run in the groove of plane A. At the same time, the remaining accelerometer gives us the interpolation reading B+, B- of the B axis, Figure 1. These readings are the output voltage which is proportional to the sine of the angle inclination, and it is related to the horizontal deviation value shown in Eqs. (6, 7, 8).

$$\begin{aligned} S_A &= \left[(A+) - (A-)\right]/2 \\ S_B &= \left[(B+) - (B-)\right]/2 \end{aligned} \tag{6}$$

In which: $A+$, $B+$ are readings of A_0 and B_0 directions; $A-$, $B-$ are readings of A_{180} and B_{180} directions; S_A, S_B are the average values of readings in two-way 0 and 180.

$$\begin{aligned} C_A &= S_A \cdot M \cdot RINT \\ C_B &= S_B \cdot M \cdot RINT \end{aligned} \tag{7}$$

In which: M is the constant, equal to 0.05 corresponding to the deviation value in millimeters and equal to 0.005 in centimeters; $RINT$ is the reading interval, this value is always 0.5 m; C_A and C_B are the values of local lateral deviation, regardless of directional angle.

$$\begin{aligned} D_A &= C_A \cos ZZ - C_B \sin ZZ \\ D_B &= C_A \sin ZZ + C_B \cos ZZ \end{aligned} \tag{8}$$

In which: ZZ is the directional angle; D_A and D_B are the horizontal deviation values considering the directional angle.

In Figure 4 we can see an example of the raw observed data of a GK-604D inclinometer up to a depth of 30 m.

With readings at a depth of 30 m that is noted in the red rectangle, we have readings of direction $A+ = 1013$, $B+ = -380$, and direction $A- = -1052$, $B- = 320$. The rounding calculation using Eq. (6), $S_A = 1033$, $S_B = -350$, continuing to apply Eq. (7) to calculate the horizontal deviation value at this position in centimeters, regardless of the directional angle ZZ, we have $C_A = 1033 \cdot 0.005 \cdot 0.5 = 2.58$ cm, $C_B = -350 \cdot 0.005 \cdot 0.5 = -0.88$ cm. The result of the A direction is illustrated in the red rectangle of Figure 5, the B direction result is not shown here.

When observing a local object, regardless of the spatial orientation angle, we can assume that pressure is directed perpendicular to the diaphragm wall, so the directional angle is $ZZ = 0°$. Then we can see that the value of D_A, D_B in formula (8) equals the value C_A, C_B. In Vietnam, displacement monitoring is mostly applied to observe the diaphragm wall in the basement. This is a locally observed object and therefore, during monitoring, it is always put the ZZ value to zero. Thus we can easily identify the displacement of the diaphragm wall following the direction of the excavation. In this case, applying formulas (7) and (8) provides the same results.

Similar to calculating with data at the depth of 29.5 m, we get the value of the A-axis deviation of $C_A = 2.41$ cm. In conformity with the principle of horizontal displacement calculated from the bottom of the monitoring pipe, we have the horizontal displacement value at

C.2 A-AXIS PROFILE DATA TEXT REPORT

Report: A-Axis Digits and Profile in Centimeters (Bottom Up)

Project Name:	myHoles	File Name:	newHole_001.gkn
Hole Name:	newHole	Reading Date:	01/02/13
Top Elevation:	186.6	Reading Time:	14:32:13
Azimuth Angle:	0.0	Probe Name:	testProbe

Elev (m)	A+ (dig.)	A- (dig.)	Sum (dig.)	Diff (dig.)	Diff/2 (dig.)	Defl (cm)	Level (m)
186.1	564	-600	-36	1164	582	139.79	0.5
185.6	559	-599	-40	1158	579	138.34	1
157.6	946	-981	-35	1927	964	7.40	29
157.1	945	-985	-40	1930	965	4.99	29.5
156.6	1013	-1052	-39	2065	1033	2.58	30

Average Channel A Offset: -17.5

Figure 5. Area of monitoring and surveillance Value of A-axis lateral deviation (Deep Excavation, 2021)

29.5m depth which is 4.99 cm, equal to the cumulative displacement from 30 m to 29.5 m, shown in the red rectangle of Figure 5.

Although still complying with the general principle, there are still differences that need attention in calculating the horizontal displacement, Digipro2 and SiteMaster software, corresponding to the Digitilt DataMateII and GK-604D instruments. Firstly, the notation convention for the monitoring axes is "0" and "180" or "+" and "-". Secondly, the device constant values need to be appropriate for the calculation formula. For application in work in Vietnam we can simplify this calculation as follows: (1) for the Digitilt DataMate II device of GeoSlope with the device constant of 25000, the value of horizontal deviation, in millimeter unit, at each monitoring point is $(A_0 - A_{180})/100$; (2) for GeoKon GK604-D equipment with the device constant of 20000, the horizontal deviation value, millimeter unit, at each monitoring point is $(A + -A-)/80$.

2.4 ICTool program

To respond well to the data processing of inclinometer systems for basement diaphragm walls in Vietnam, the ICTool program has been developed to calculate the monitoring data of the GK-604D and DataMate II devices. The workflow of ICTool, as illustrated in Figure 6, incorporates several important features.

For instance, the raw data file (input data) will be the source of information that allows the program to automatically identify the type of device used and automatically select the instrument constant as well as the matching principle. It then calculates the parameters that access cumulative deviation (known as an absolute position) and/or cumulative displacement of inclinometers. Once the reference epoch is selected, result graphs and data are plotted and displayed on the interface. In addition, the program is also able to export the results into reports. Exploring the full capabilities of the ICTool program, the installer along with sample data has been uploaded to the OSF website (ICTool, 2023).

3 Experimental results and discussion

Evaluating the calculation ability and the efficiency of the ICTool program, the observed data of the Geokon GK-604D instrument was calculated by ICTool, Digipro2, and Sitemaster 2012 software. The experimental site for monitoring the displacement of the diaphragm wall in the basement is located at 165 Xa Dan, Hanoi. At this site, the 800 mm thick diaphragm wall system was used as a retaining structure for the excavation using the top-down method. There are 9 boreholes which are arranged inside diaphragm wall plates with depths from 26.5 m to 27.5 m, as depicted in Figures 7 and 8.

The excavation was conducted in three stages to the 1st, 2nd, and 3rd floors of the basement at depths of -4.00 m, -8.5 m, and -13.00 m, respectively. Following the geological conditions described

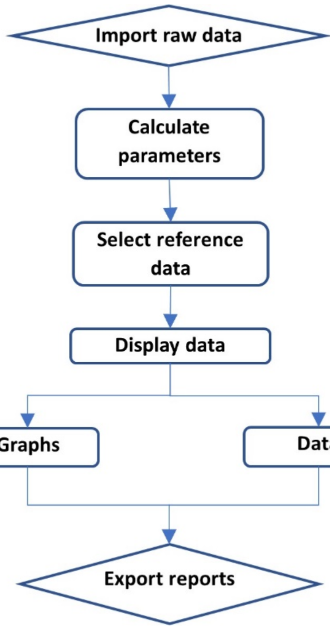


Figure 6. Workflow of ICTool program

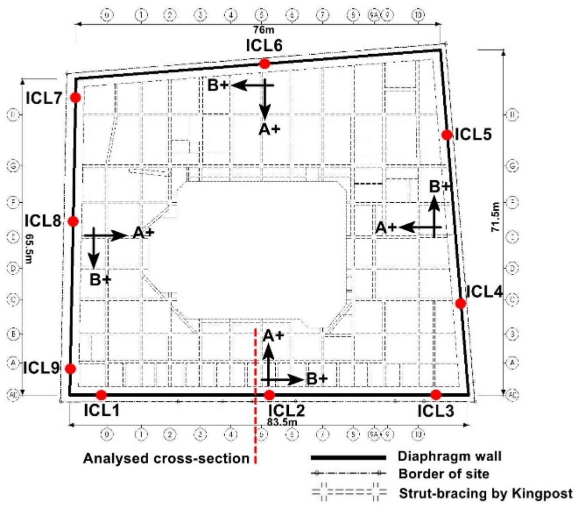


Figure 7. Diagram of the excavation retaining wall structure with inclinometer borehole positions

in Figure 8, Kingpost strut-bracing systems were installed upon completion of the excavation for phases 1 and 2 to stabilize the diaphragm wall.

The process of monitoring was performed in 9 cycles from 30/12/2016 to 09/08/2017 with observation frequency of about one month. The raw data of the borehole named ICL2 was selected to process (ICTool, 2023).

In the simplest case, we have processed the raw data for the first and the second cycles, in Table 1, which represents the corresponding times before excavation and after completing the first stage of excavation at a depth of -4.00 m. The instrument constants in DigiPro2 are configured to a value of 20000 as specified in the guidance provided by GeoKon. In addition, SiteMaster 2012 is always by default, while in ICTool, the raw data format is automatically identified and applied. Ignoring the unstable value at the pipe top, the results of cumulative displacement for the A axis are summarized in Table 2.

Calculating the cumulative displacement using ICTool in Figure 9, and SiteMaster 2012 gives a calculation difference of about

Table 1. Raw data of the first cycle (December 30, 2016) and the second cycle (January 20, 2017) of the ICL2 borehole

***	***
GK 604M(v1.3.0.8,02/17);2.0;FORMAT II	GK 604M(v1.3.0.8,02/17);2.0;FORMAT II
PROJECT :165xd	PROJECT :165xd
HOLE NO. :ICL2	HOLE NO. :ICL2
DATE :12/30/16	DATE :1/20/17
TIME :9:19:53	TIME :10:29:53
PROBE NO.:1609783	PROBE NO.:1609783
FILE NAME:i2_001.gkn	FILE NAME:i2_002.gkn
#READINGS:57	#READINGS:57
FLEVEL, A+, A-, B+, B-	FLEVEL, A+, A-, B+, B-
27.5, 677, -733, 758, -742	27.5, 681, -734, 769, -753
27.0, 651, -705, 739, -744	27.0, 655, -709, 749, -722
26.5, 635, -689, 721, -680	26.5, 639, -693, 731, -690
26.0, 631, -691, 729, -687	26.0, 633, -693, 739, -696
25.5, 611, -672, 727, -690	25.5, 615, -677, 737, -700
25.0, 522, -644, 722, -688	25.0, 521, -642, 732, -698
24.5, 582, -635, 775, -734	24.5, 586, -639, 785, -744
24.0, 564, -620, 734, -689	24.0, 567, -623, 744, -689
23.5, 550, -602, 625, -579	23.5, 554, -606, 633, -589
23.0, 515, -578, 437, -426	23.0, 512, -575, 447, -436
22.5, 472, -530, 191, -202	22.5, 475, -533, 201, -212
22.0, 426, -498, -102, 63	22.0, 432, -504, -92, 53
21.5, 403, -460, -514, 534	21.5, 402, -459, -504, 514
21.0, 370, -428, -749, 782	21.0, 374, -432, -739, 772
20.5, 332, -382, -930, 941	20.5, 332, -383, -920, 961
20.0, 287, -333, -1026, 1060	20.0, 291, -337, -1016, 1049
19.5, 258, -309, -1027, 1039	19.5, 255, -306, -1017, 1039
19.0, 216, -292, -920, 955	19.0, 221, -297, -910, 950
18.5, 214, -271, -701, 732	18.5, 219, -276, -691, 729
18.0, 165, -221, -541, 581	18.0, 166, -222, -532, 572
17.5, 87, -149, -368, 408	17.5, 93, -155, -358, 398
17.0, 37, -92, -211, 248	17.0, 30, -85, -201, 238
16.5, -32, -17, -74, 114	16.5, -25, -24, -64, 104
16.0, -67, 18, 31, -5	16.0, -71, 22, 41, -15
15.5, -110, 57, 122, -88	15.5, -115, 62, 98, -73
15.0, -116, 63, 98, -61	15.0, -116, 62, 98, -61
14.5, -115, 57, 122, -88	14.5, -113, 55, 132, -98
14.0, -90, 32, 162, -129	14.0, -92, 34, 172, -139
13.5, -52, 1, 193, -169	13.5, -56, 4, 203, -179
13.0, -19, -25, 194, -174	13.0, -17, -27, 207, -184
12.5, 29, -74, 179, -148	12.5, 33, -78, 189, -158
12.0, 80, -136, 164, -109	12.0, 84, -140, 174, -119
11.5, 160, -217, 128, -63	11.5, 163, -220, 138, -73
11.0, 229, -289, 83, -26	11.0, 237, -297, 94, -36
10.5, 301, -346, 46, 18	10.5, 308, -353, 56, 8
10.0, 319, -374, 33, 32	10.0, 328, -383, 43, 22
9.5, 330, -384, 36, -8	9.5, 337, -391, 46, -18
9.0, 331, -383, 102, -60	9.0, 334, -386, 112, -70
8.5, 320, -377, 163, -131	8.5, 323, -380, 173, -141
8.0, 321, -374, 223, -193	8.0, 323, -376, 233, -207
7.5, 346, -402, 287, -258	7.5, 340, -396, 297, -268
7.0, 320, -367, 332, -308	7.0, 336, -383, 342, -318
6.5, 295, -351, 388, -339	6.5, 293, -349, 398, -349
6.0, 312, -371, 399, -353	6.0, 317, -376, 409, -363
5.5, 329, -385, 416, -363	5.5, 330, -386, 426, -373
5.0, 319, -372, 422, -379	5.0, 327, -380, 432, -389
4.5, 311, -369, 411, -354	4.5, 329, -387, 421, -364
4.0, 280, -325, 415, -368	4.0, 305, -350, 425, -378
3.5, 231, -300, 334, -286	3.5, 255, -324, 344, -296
3.0, 232, -290, 144, -101	3.0, 254, -312, 154, -111
2.5, 211, -263, -54, 41	2.5, 233, -285, -44, 31
2.0, 189, -248, -243, 240	2.0, 214, -273, -233, 230
1.5, 156, -215, -358, 393	1.5, 177, -235, -348, 383
1.0, 121, -192, -446, 508	1.0, 134, -205, -436, 498
0.5, 115, -174, -490, 559	0.5, 124, -183, -480, 549
0.0, -734, NaN, -753, NaN	0.0, -734, NaN, -753, NaN

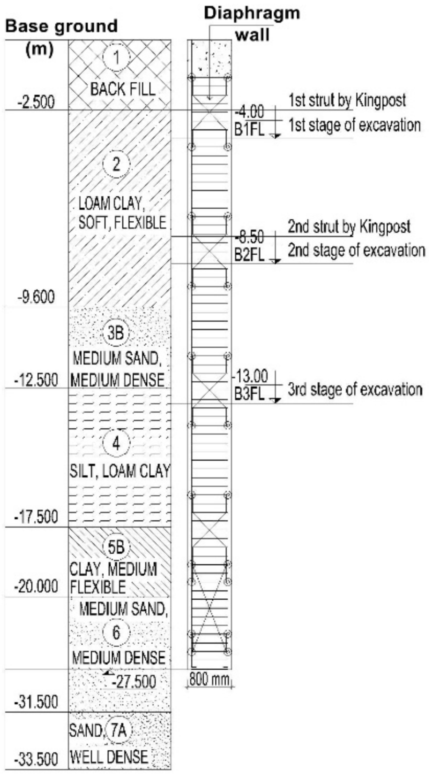


Figure 8. ICL2 analysed cross-section – geotechnical conditions and construction elements

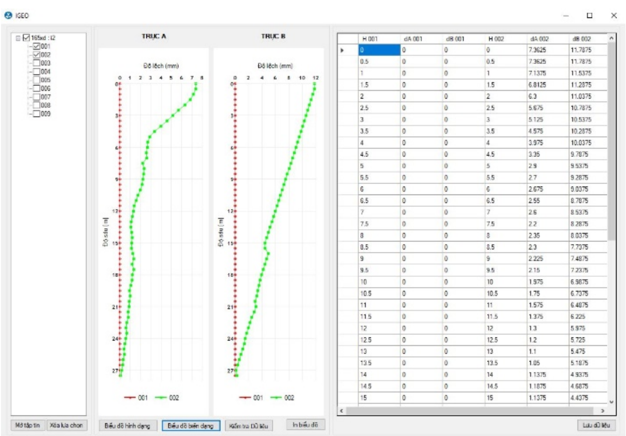


Figure 9. Ploted and calculated cumulative displacement using ICTool between the first and the second cycles

Table 2. Summary of data processing of ICL2 inclinometer in-situ

Depth [m]	Cumulative displacement [mm]			Calculation deviation [mm]		
	ICTool (ICT)	SiteMaster 2012 (SM)	Digipro2 (DP)	ICT-SM	ICT-DP	SM-DP
0.5	7.36	7.30	14.73	0.06	-7.37	-7.43
1	7.14	7.10	14.28	0.04	-7.14	-7.18
1.5	6.81	6.80	13.63	0.01	-6.82	-6.83
2	6.30	6.20	12.60	0.10	-6.30	-6.40
2.5	5.68	5.60	11.35	0.08	-5.68	-5.75
3	5.13	5.10	10.25	0.03	-5.13	-5.15
3.5	4.58	4.50	9.15	0.08	-4.58	-4.65
4	3.98	3.90	7.95	0.08	-3.98	-4.05
4.5	3.35	3.30	6.70	0.05	-3.35	-3.40
5	2.90	2.80	5.80	0.10	-2.90	-3.00
5.5	2.70	2.60	5.40	0.10	-2.70	-2.80
6	2.68	2.60	5.35	0.07	-2.68	-2.75
6.5	2.55	2.50	5.10	0.05	-2.55	-2.60
7	2.60	2.50	5.20	0.10	-2.60	-2.70
7.5	2.20	2.10	4.40	0.10	-2.20	-2.30
8	2.35	2.30	4.70	0.05	-2.35	-2.40
8.5	2.30	2.20	4.60	0.10	-2.30	-2.40
9	2.23	2.20	4.45	0.02	-2.23	-2.25
9.5	2.15	2.10	4.30	0.05	-2.15	-2.20
10	1.98	1.90	3.95	0.08	-1.98	-2.05
10.5	1.75	1.70	3.50	0.05	-1.75	-1.80
11	1.58	1.50	3.15	0.08	-1.58	-1.65
11.5	1.38	1.30	2.75	0.08	-1.38	-1.45
12	1.30	1.20	2.60	0.10	-1.30	-1.40
12.5	1.20	1.10	2.40	0.10	-1.20	-1.30
13	1.10	1.00	2.20	0.10	-1.10	-1.20
13.5	1.05	1.00	2.10	0.05	-1.05	-1.10
14	1.14	1.10	2.27	0.04	-1.13	-1.17
14.5	1.19	1.10	2.37	0.09	-1.18	-1.27
15	1.14	1.10	2.27	0.04	-1.13	-1.17
15.5	1.13	1.10	2.25	0.02	-1.13	-1.15
16	1.25	1.20	2.50	0.05	-1.25	-1.30
16.5	1.35	1.30	2.70	0.05	-1.35	-1.40
17	1.18	1.10	2.35	0.08	-1.18	-1.25
17.5	1.35	1.30	2.70	0.05	-1.35	-1.40
18	1.20	1.10	2.40	0.10	-1.20	-1.30
18.5	1.18	1.10	2.35	0.08	-1.18	-1.25
19	1.05	1.00	2.10	0.05	-1.05	-1.10
19.5	0.93	0.90	1.85	0.03	-0.93	-0.95
20	1.00	0.90	2.00	0.10	-1.00	-1.10
20.5	0.90	0.80	1.80	0.10	-0.90	-1.00
21	0.89	0.80	1.77	0.09	-0.88	-0.97
21.5	0.79	0.70	1.57	0.09	-0.78	-0.87
22	0.81	0.70	1.63	0.11	-0.82	-0.93
22.5	0.66	0.60	1.33	0.06	-0.67	-0.73
23	0.59	0.50	1.17	0.09	-0.58	-0.67
23.5	0.66	0.60	1.33	0.06	-0.67	-0.73
24	0.56	0.50	1.13	0.06	-0.57	-0.63
24.5	0.49	0.40	0.97	0.09	-0.48	-0.57
25	0.39	0.30	0.77	0.09	-0.38	-0.47
25.5	0.43	0.40	0.85	0.03	-0.43	-0.45
26	0.31	0.20	0.62	0.11	-0.31	-0.42
26.5	0.26	0.20	0.52	0.06	-0.26	-0.32
27	0.16	0.10	0.32	0.06	-0.16	-0.22
27.5	0.06	0.00	0.13	0.06	-0.07	-0.13
28			0.00			0.00

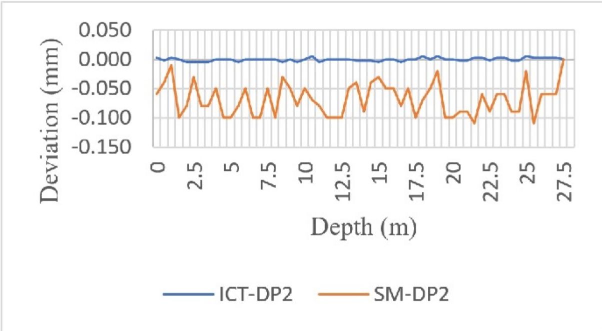


Figure 10. Calculation difference of ICTool and SiteMaster 2012 in comparison with DigiPro2 applied a device constant of 40000 for the first and second cycles

0.1 mm while the calculated value by DigiPro2 is completely different. The cause of tiny differences between ICTool and SiteMaster 2012 can be attributed to the rounding during the calculation and is completely acceptable. In the data processing using Digipro2, some differences have been pointed out. Firstly, with the monitoring data at the depth of 27.5 m, SiteMaster 2012 and ICTool will assign "0" to this value and start calculating the cumulative displacement from the point with the depth of 27 m while the DigiPro2 will assign "0" to the data at the depth of 28 m and start calculating the cumulative displacement from data at the depth of 27.5 m. This has shown that in the lateral displacement component at each depth point there is a systematic difference of approximately 0.13 mm.

In addition, Table 2 shows that the cumulative displacement value of DigiPro2 is about twice that of the two others. For this reason, we reset the instrument constant to the value of 40000 during the data processing for DigiPro2. Figure 10 shows the calculation differences between the ICTool and the DigiPro2 software (ICT-DP2) which has a maximum value of less than 0.005 mm while the maximum value (SM-DP2) between SiteMaster 2012 and DigiPro2 is about 0.10 mm. These deviations are very tiny in comparison with bias and measuring errors (Grodecki et al., 2018; Moffat et al., 2019) or technical requirements (Liu et al., 2011; Pei et al., 2021) of basement diaphragm wall monitoring so they can be omitted.

The calculations were extended with raw data of 9 cycles of the ICL2 pipe using ICTool and then compared with the calculation results according to DigiPro2. Get assignment "0" point at the depth of 28 m, obtained results as shown in Figure 11. The calculated difference between the two software in Figure 11 is very small, within ± 0.005 mm. This indicates that when processing data of the Geokon GK-604D device using DigiPro2 software, it is necessary to set up the instrument constant to 40000. In a similar comparison between ICTool and SiteMaster, the calculation difference is within 0.24 mm, which is not shown here. This was explained above by rounding the number and choosing the reference point position at the bottom of the casing.

ICTool had also been used to process many other data of the Geokon GK-604D instrument. The processing results are equivalent to SiteMaster 2012 and DigiPro2, meeting the technical requirements of the horizontal movement monitoring of the basement walls in Vietnam.

4 Conclusion

Although the general principle of calculating the inclinometer displacement is simple, it requires a thorough understanding to avoid mistakes with observed data coming from different types of equipment or the application of computational processing software. With the most popular instruments in Vietnam today, it can be applied to two devices: (1) with Digitilt DataMate II instrument, the horizontal deviation value in millimeters equal to $(A_0 - A_{180})/100$; (2) with GK-604D instrument corresponding equals $(A+ - A-)/80$. In the case of GK-604D data processing with DigiPro2, it is necessary to set the device constant to 40000.

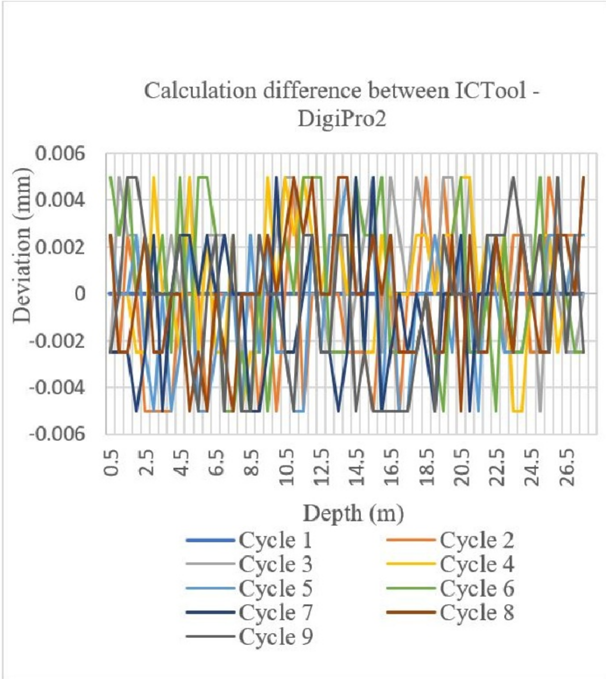


Figure 11. Calculation difference of ICL 2 between ICTool and DigiPro2 applied device constant of 40000 for 9 cycles

ICTool has been tested and used to process a lot of Geokon GK-604D data in the movement monitoring of the basement diaphragm wall. ICTool only focuses on calculating cumulative displacement in the direction of pressure on basement diaphragm walls and brought the equivalent results to SiteMaster 2012 or DigiPro2 with a note of the adjusted instrument constant. It allows surveyors to process the diaphragm wall displacement data in Vietnam more conveniently.

DigiPro2 and SiteMaster 2012 (now version 2018) are commercial software that are expensive and carry a limited trial period (30 days for SiteMaster 2012 and 45 days for Digipro2). ICTool was built and will be provided free of charge for the communication of the monitoring of basement diaphragm wall displacement in Vietnam (ICTool, 2023).

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