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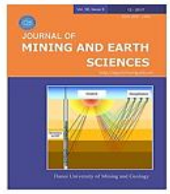

Creating a program for calculating horizontal deformations in depth using an inclinometes sensors

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ABSTRACT

In underground block-caving operations and while realized construction pits will create empty gaps underground, thus which changed change the stress state and groundwater table in the ground. Horizontal shifts of the soil that cause damage to structures may occur. The application of inclinometer equipment will can detect the horizontal deformation in depth and can early warn dangerous deformation. In our country, measuring horizontal movement by magnetic sensor is quite new. The processing of monitoring data acquired by sensor is still mainly depend on the licensed software with the high cost. The current, in Vietnam, only one software is written to processing data but it can not handle measurement data of different machine models which have different data formats. Meanwhile, users always wished to use a software that can handle measurement data from various types of machines of different firms with different data file formats and low cost. This article refers to the way of creating a program to calculate deformation horizontal in depth by using Inclinometer equipment.

1. Introduction

In 1957, Stanley D. Wilson, who is inclinometer inventor and Slope Company's Co-Founder, has used inclinometer to monitor movement of the Greenland Ice Cap. The inclinometer first became commercially available in the late 1950s from the SlopeIndicator Company which Stan Wilson founded (Green and Mikkelsen, 1986, 1988). The inclinometer devices are used for the following purposes:

- Determine the movement of the underground object to issue a warning;
- Check the deformation of objects during construction underground to confirm the distortion does not affect the surrounding objects. Check for ground movement and deformation during construction;
- Check dam's stability and related objects;
- Monitoring stability of embankments, foundations and other objects etc.;
- Monitoring deformation in the mining area.

In underground block-caving operations and while realized construction pits, horizontal shifts of the soil that cause damage to structures may

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occur. So, it is necessary to proceed inclination measurements to map any horizontal soil shifts. Inclinometer devices are used to measure movements and deformations in ground and in structures underground. It also used to early warning for possible deformation at the mines. At this time, there have been some case studies such as:

Research the method of monitoring using magnetic sensor (Wilson, Hilts, 1972; Green, Mikkelsen, 1988; Dunnicliff, 1988; Abramson, 2002; Cornforth, 2005; Timothy, 2008; Durham Geo-Interprisec Inc. 2011, 2014) and proposed limit values for horizontal movement to set design, construction and quality control standards (ASTM D6230, 1998; JGJ, 1999; Christian, 2004; ASTM D 7299, 2007). From 2003 to 2013, in (Mikkelsen, 2003; Karen et al., 2005; Rahman, Taha, 2005; Ou et al., 2013; Ou, 2013) had researched the methods to analyse and evaluate all elements could effected to measurement results. Data processing is mainly done by the well-known manufacturers such as Durham Geo Slope Indicator, RST Instruments, Geokon, etc, with a very high-cost (from 15 to 25 thousand dollars, included software and hardware). In the past 15 years, the rapid growing up of information technology has greatly improved the processing speed of the computers, thereby facilitating the scientists, geodesic-mapping engineer easier on programming can meet the needs of practical. However, the content of the studies published above shows that the analysis and processing of horizontal movement data mainly depend on the license software accompanying with the device used in the project only. The articles, case studies, data processing software of the individuals and organizations mentioned above only provided the principles of measurement, standards, methods of measurement, methods of analyzing measurement results and Packaged software with software manuals (if you purchase the full package of sensing devices to carry out projects, studies). On the other hand, each vendor provide their own software, which handles the measured data of the device itself produced in its own data format. This is considered a major issue that interfere with the algorithms in the software to bind users of device manufacturers and software. However, in the other countries, when implementing a project, the initial investment cost using to purchase equipment and software is required within the project budget. Thus, researching and developing software to analyse measurement data is not interested.

Nowadays, in Vietnam, one of the most priority is researching the application of new technologies to promote economic development. The application of modern equipment such as magnetic sensors in horizontal movement monitoring allows to significantly reduce time, workload, low cost, high automation from measurement, analysis, prediction, and data management. Thus, the monitoring horizontal movement by sensing devices has been interested in more than five years, as the following basic research directions:

In (Ministry of Transport of Vietnam 2011, 2013; No. 384/QD-BGTVT) it is only mentioned that, in order to detect the deformation of the hinge may use an inclinometer, without any other indication. In (Thai Cong Dinh et al., 2002) introduce the principle of installation and operation of sensor observation devices. From 2012 to 2014, in (Hoang Xuan Thanh, Bui Thi Kien Trinh, 2010) research the use of magnetic sensors to monitor the deformation movement of the construction. In (Tran Ngoc Dong, Doan Duc Nhuan, 2012; Tran Ngoc Dong, 2014) using geodetic devices to monitor the surface of the object, underground statistic, measuring by sensor and data processing based on the software supplied with foreign survey equipment, integrating the two results to calculate the horizontal movement value. In 2015, (Ly Thi Minh Hien et al.) analysis the automatic horizontal movement by AFID 1.0 software based on observation data for early warning of riverine erosion. However, the AFID version 1.0 software was developed to allow the analysis of horizontal displacement data from Geokon 6000-1M.

Thus, we can be see, in our country, measuring horizontal movement by magnetic sensor is quite new. The processing of monitoring data acquired by sensor is still mainly depend on the licensed software with the high cost. In Vietnam, only one software is written to processing data (Ly Thi Minh Hien, 2015), but it only handles measurement data of a certain measuring line of Geokon equipment, it can not handle measurement data of different machine models which have different data formats. Meanwhile, users always wished to use a software that can handle measurement data from various types of machines of different firms with different data file formats and low cost. This article refers to the way of creating a program to calculate deformation horizontal in depth by using Inclinometer equipment.

2. Method

Inclinometer devices used to measure horizontal displacements according to depth of a borehole. An inclinometer system has three components: casing, an inclinometer measurement system and software (Durham Geo Slope Indicator, 2011, 2014; RST Instruments Ltd.). The classic system includes classic control cable, classic probe and the readout (http://www.slopeindicator.com/instruments/inclin-digitilt-classic.php). The modern system includes a digital probe, control cable, a cable gate, a bluetooth reel, readout unit (see Figure. 1, http://www.slopeindicator.com/instruments/inclin-digitilt-at.php).

Follow (https://www.iitbhu.ac.in/faculty/min/rajesh-rai/NMEICT-Slope/lecture/c9/l8.html), "The components of the inclinometer are a plastic casing with four longitudinal grooves cut in the inside wall, and a probe that is lowered

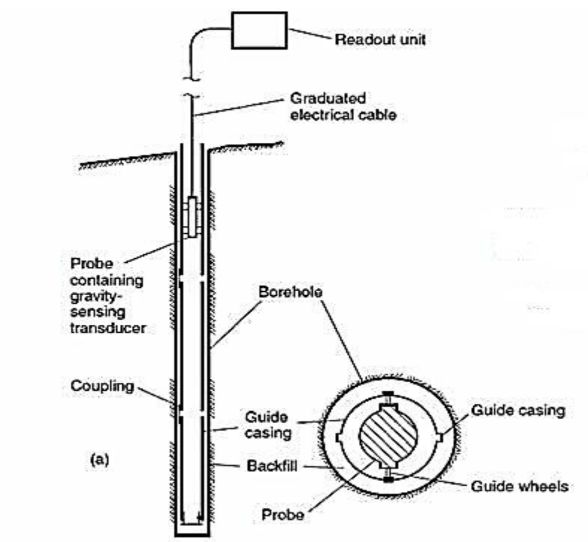

Figure 1. Arrangement of grooved casing and inclinometer probe (Dunnicliff, 1993).

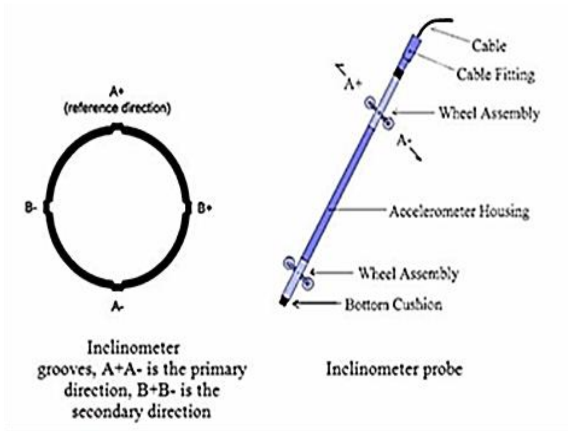

Figure 2. Various components of inclinometers.

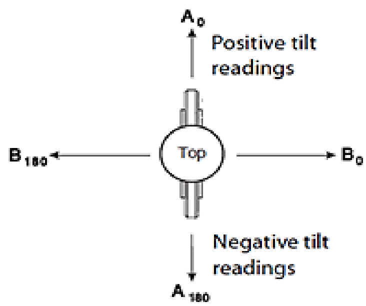

Figure 3. Measurement planes.

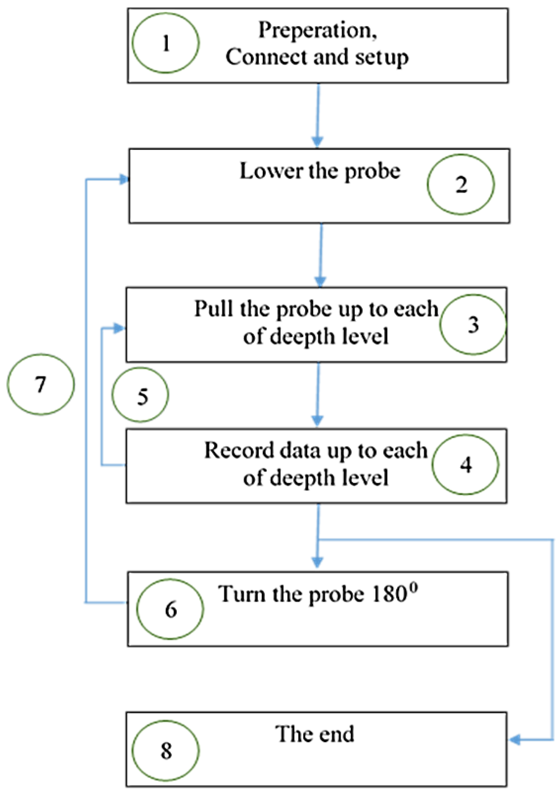

Figure 4. Measurement processing (Dinh, 2016).

down the casing on an electrical cable with graduated depth markings", see Figure. 2.

The probe has two wheels that run in the grooves of the casing. It nesscessary to maintain stability when read the number. In (Durham Geo Slope Indicator, 2011), see Figure. 3, when the probe is tilted toward the A0 or B0 direction, readings are positive and vice versa.

Technological measurement process for measuring deformation along the depth by sensors inclinometers are proposed in the Figure 4, include 8 steps:

3. Data processing algorithms

In Digitilt Inclinometer Probe Manual (2011), the side opposite the tilt angle θ is deviation, determined by the following formula see Figure. 5a:

$$d_i = L.sin\theta_i, \quad (2)$$

where: di - side opposite the angle θ; L - measurement interval; θ_i - angle of inclination.

Instead of measuring the angle, just measure the distance, which will determine the deviation value at each measurement interval, see Figure. 5b (Digitilt Inclinometer Probe Manual, 2011).

After studying the principles and processes of data processing, the authors had set up the block diagram of the program as Figure 6.

In the diagram above:

•A_{0i}, A_{180i}, B_{0i}, B_{180i} : The measured values direct to A, B axes, number i;

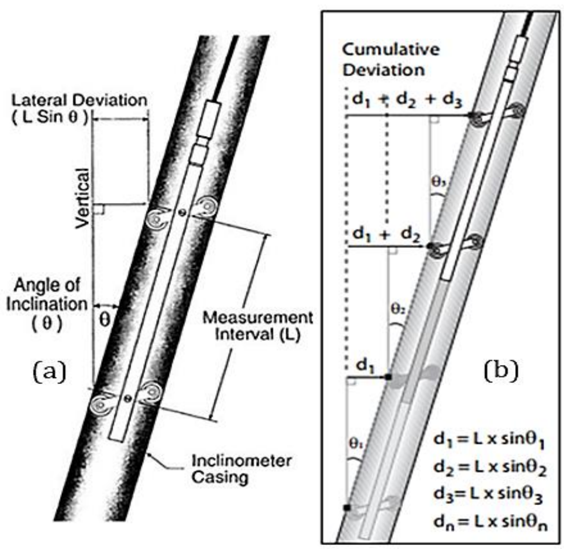

Figure 5. Principles define horizontal shift by inclinometer. (a) (b)

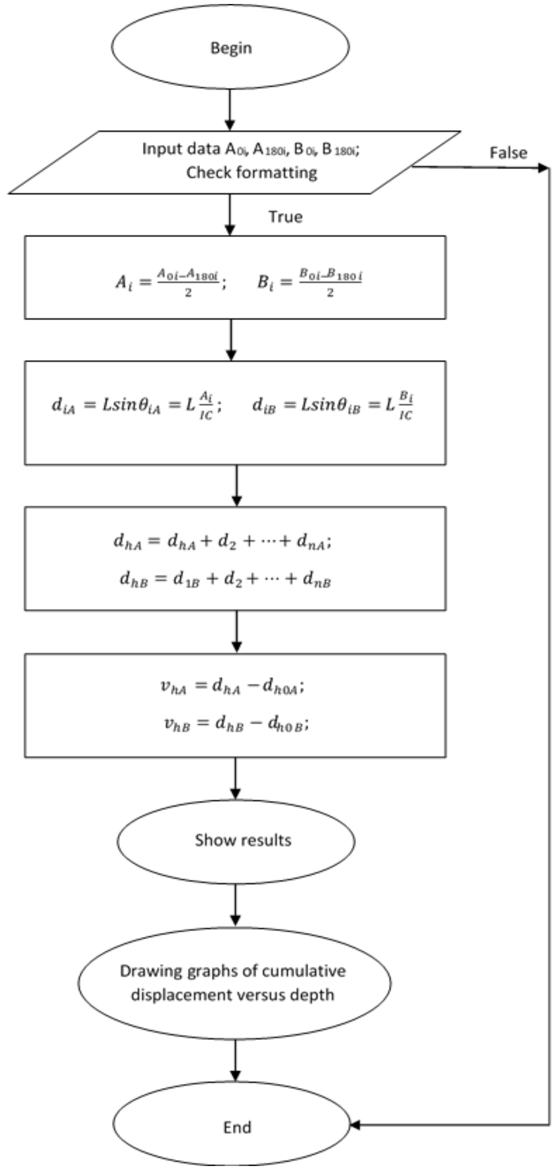

Figure 6. Block diagram of the program.

•A_i : Average measurement value direct to A axes, number i;

•d_i : the value of the horizontal movement direct to the horizontal axis, number i;

•d_h :the cumulative deviation value at the height h, d_{ho} is the cumulative deviation value at the height h position of the first cycle;

•v_{hA}, v_{hB} :the horizontal movement value at the height h compared to the first cycle.

The devices and software are provided by manufacturers of inclinometer probes to be compatible with their systems. Although using different software, the process of data processing must also be done through the basic steps was proposed in the Figure. 7, includes:

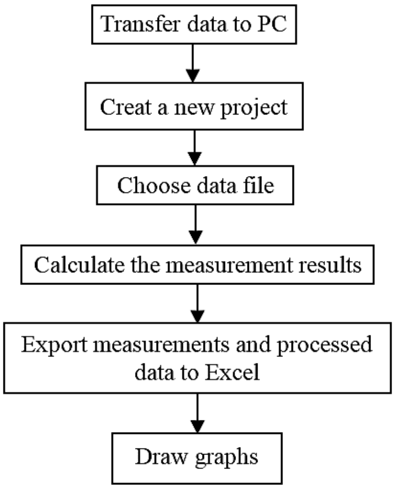

Figure 7. Processing of data (Dinh, 2016).

4. Creating a program for calculating horizontal deformations

After studying the processes of data processing and set up block diagram, the authors of the paper has set up a program for calculating horizontal deformations with the name InclinometerSoft. The InclinometerSoft software is written in the Microsoft Visual Studio Express 2013 programming language a Microsoft's software. The reason why the team chose this programming language because Microsoft Visual Studio Express 2013 is a clear, easy-to-understand language; Intuitive, easy to use interface; Have a solid background in object modeling as other powerful programming languages. Here are some of the basic codes of the InclinometerSoft program written by the article authors's:

```
* Code "Load Data":
Private Sub CmdOk_Click(sender As Object, e As EventArgs) Handles
CmdOk.Click
  If FrmInclinometer.AddSur = True Then
    FrmInclinometer.CKCounts = FrmInclinometer.CKCounts + 1
    ReDim Preserve
FrmInclinometer.Chuky(FrmInclinometer.CKCounts)
FrmInclinometer.TVThumuc.Nodes.Add(DTPSurveyDate.Value)
    FrmInclinometer.CKSelect = FrmInclinometer.CKCounts
  Else
    FrmInclinometer.TVThumuc.SelectedNode.Text =
DTPSurveyDate.Value
    FrmInclinometer.CKSelect =
FrmInclinometer.ReadingSet(FrmInclinometer.TVThumuc.Selected
Node.Index + 1)
  End If
  FrmInclinometer.AddOrEditSurvey()
  FrmInclinometer.TB1.SelectTab(2)
  CmdCancel.PerformClick()
 End Sub
```

```
* Code Find_MaxA
Sub Tinh_MaxA()
  Dim i, j, k As Integer
  MaxA = 0
  For i = 1 To CKSelectsA
   j = ReadingSetA(i)
   For k = 1 To PCs(CKOriginA).NumDepths
    If Math.Abs(PCs(j).CA(k)) > MaxA Then MaxA =
Math.Abs(PCs(j).CA(k))
   Next
  Next
 End Sub
* Sub Load_Survey_A()
  Dim i, j As Integer
  DGVSurveys.Rows.Clear()
  For i = 1 To CKCounts
   DGVSurveys.Rows.Add(PCs(i).SurveyDate, False, False)
  Next
  For i = 1 To CKSelectsA
   j = ReadingSetA(i)
   If j = CKOriginA Then
    DGVSurveys.Rows(j - 1).Cells(1).Value = False
    DGVSurveys.Rows(j - 1).Cells(2).Value = True
   Else
    DGVSurveys.Rows(j - 1).Cells(1).Value = True
    DGVSurveys.Rows(j - 1).Cells(2).Value = False
   End If
  Next
 End Sub
* Code calculate vh
 Sub Tinh_vA()
  Dim i, j, k As Integer
  MaxA = 0
  For i = 1 To CKSelectsA
   j = ReadingSetA(i)
   For k = 1 To PCs(CKOriginA).NumDepths
    PCs(j).DCA(k) = PCs(j).CA(k) - PCs(CKOriginA).CA(k)
    If Math.Abs(PCs(j).DCA(k)) > MaxA Then MaxA =
Math.Abs(PCs(j).DCA(k))
   Next
  Next
 End Sub
* Code drawing Charts:
Sub Load_Chart_A()
  Dim i, j As Integer
  Dim vA As Double
  Dim Text As String
  Dim h As Date
  ChartA.Series.Clear()
  ChartA.Titles("TA").Text = FrmInclinometer.SiteName & " " &
FrmInclinometer.Inclinometer & " A"
  ChartA.Titles("TA").Docking =
DataVisualization.Charting.Docking.Top
  If FrmInclinometer.DepthUnits = "Meters" Then
   ChartA.ChartAreas("ChartA").AxisX.Title = "Profile Change vs
Time in mm"
   ChartA.ChartAreas("ChartA").AxisY.Title = "Date"
  Else
   ChartA.ChartAreas("ChartA").AxisX.Title = "Profile Change vs
Time in Inches"
   ChartA.ChartAreas("ChartA").AxisY.Title = "Date"
  End If
  ChartA.ChartAreas("ChartA").AxisX.TitleAlignment =
StringAlignment.Center
  ChartA.ChartAreas("ChartA").AxisY.TitleAlignment =
StringAlignment.Center
  Dim maxA1 As Single
  maxA1 = MaxA
  If MaxA <= 1 Then
```

```
   MaxA = 1
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 4
  ElseIf MaxA <= 4 Then
   MaxA = 4
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 4
  ElseIf MaxA <= 10 Then
   MaxA = 10
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 4
  ElseIf MaxA <= 100 Then
   MaxA = Math.Round(MaxA / 10)
   If MaxA * 10 < maxA1 Then MaxA = MaxA + 1
   If MaxA Mod 2 = 1 Then MaxA = MaxA + 1
   MaxA = MaxA * 10
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 4
  ElseIf MaxA <= 1000 Then
   MaxA = Math.Round(MaxA / 100)
   If MaxA * 100 < maxA1 Then MaxA = MaxA + 1
   MaxA = MaxA * 100
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 2
  ElseIf MaxA <= 10000 Then
   MaxA = Math.Round(MaxA / 1000)
   If MaxA * 1000 < maxA1 Then MaxA = MaxA + 1
   MaxA = MaxA * 1000
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 2
  ElseIf MaxA <= 100000 Then
   MaxA = Math.Round(MaxA / 10000)
   If MaxA * 10000 < maxA1 Then MaxA = MaxA + 1
   MaxA = MaxA * 10000
   ChartA.ChartAreas("ChartA").AxisX.Interval = MaxA / 2
  End If
  ChartA.ChartAreas("ChartA").AxisX.Minimum = -MaxA
  ChartA.ChartAreas("ChartA").AxisX.Maximum = MaxA
  ChartA.ChartAreas("ChartA").AxisY.IntervalType =
DataVisualization.Charting.ChartValueType.Date
  ChartA.ChartAreas("ChartA").AxisY.Minimum =
PCs(ReadingSetA(1)).SurveyDate.Date.ToOADate
  ChartA.ChartAreas("ChartA").AxisY.Maximum =
PCs(ReadingSetA(CKSelectsA)).SurveyDate.Date.ToOADate
  ChartA.ChartAreas("ChartA").AxisX.IntervalType =
DataVisualization.Charting.DateTimeIntervalType.Number
ChartA.ChartAreas("ChartA").AxisX.RoundAxisValues()
  ChartA.Legends("Leg1").Docking =
DataVisualization.Charting.Docking.Top
  Text = Format(FrmInclinometer.TopDepth, "0.0") & " to " &
Format(FrmInclinometer.BottomDepth, "0.0")
  ChartA.Series.Add(Text)
  ChartA.Series(Text).ChartType =
DataVisualization.Charting.SeriesChartType.Line
  ChartA.Series(Text).BorderWidth = 3
  For i = 1 To CKSelectsA
   j = ReadingSetA(i)
   vA = PCs(j).TimeA
   h = Format(PCs(j).SurveyDate, "MM/dd/yyyy")
   ChartA.Series(Text).Points.AddXY(vA, h)
  Next
  Dim A1, A2 As Double
  A1 = ChartA.ChartAreas("ChartA").AxisY.Minimum
  A2 = ChartA.ChartAreas("ChartA").AxisY.Maximum
 End Sub
```

5. Experiment

To verify the InclinometerSoft software, the authors conducted experiments on the measurement of 5 cycles at a test site (HoL2 (ICL4)) - Ha Lam coal mine, Quang Ninh Province. Measurements are processed in two different software products: DigiPro2 by Durham Geo Slope Indicator, Inc and InclinometerSoft.

5.1. Data processing use DigiPro2 software

DigiPro2 is a software that monitors data movement across the Inclinometer sensor of Slope Indicator. This software has a familiar and easy-to-use interface. The results data processing by DigiPro2 software are presented in Table 1:

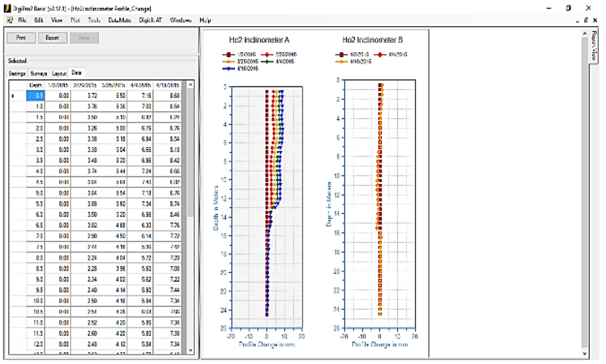

Figure. 8. The results data processing by DigiPro2 software.

Table 1. Results of the greatest values of the shifting position monitoring and the corresponding depth of observation positions.

Cycles	Maximum displacement (mm)	Corresponding depth (m)
CK01-CK02	3.88	5.5
CK01-CK03	5.64	4.5
CK01-CK04	7.40	4.5
CK01-CK05	8.82	4.5

Export button to output the calculation results in * .csv file format. The Print button has the function of outputting calculations and graphs that compare the shift between cycles in PDF format. The result will be displayed on the screen interface as shown in Figure. 8.

5.2. Data processing using InclinometerSoft software

The process of handling data measured by the InclinometerSoft software is described as follows:

Step 1: Create project (see Figure. 9.)

Step 2: Set up the basic parameters for the Inclinometer (see Figure. 10.)

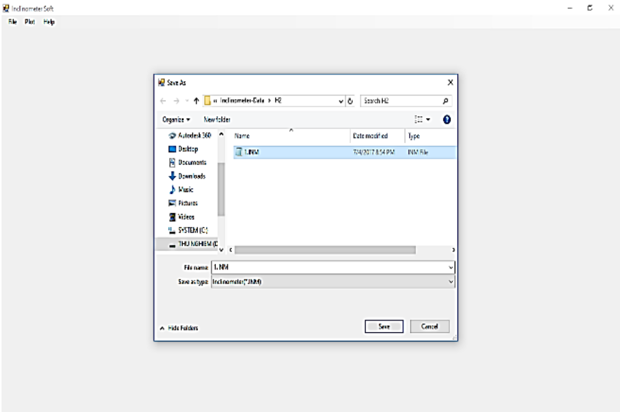

Figure. 9. Create a new project.

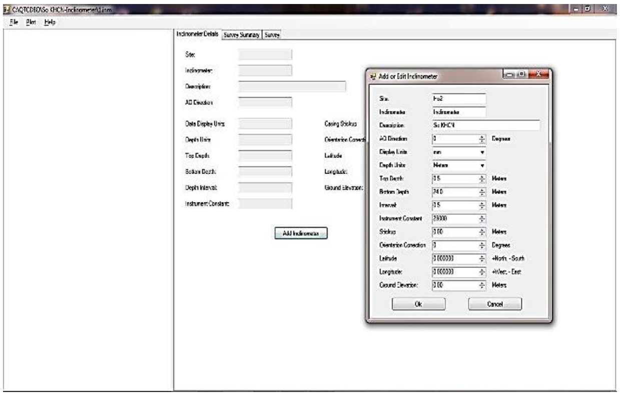

Figure. 10. Set up parameters.

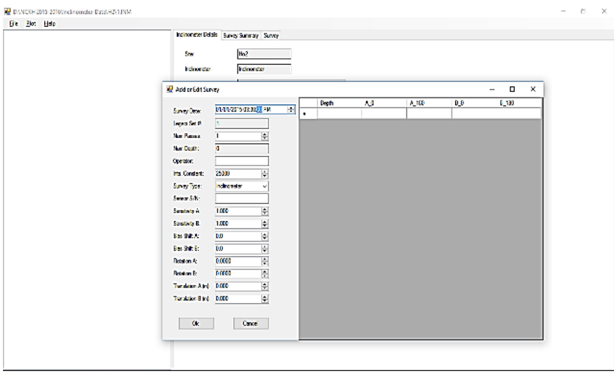

Figure. 11. Set up of a measuring cycle.

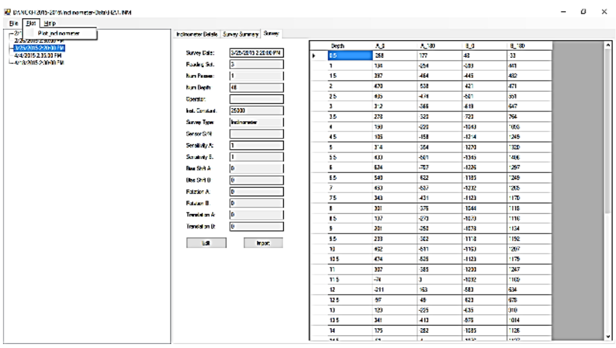

Figure. 12. Display data.

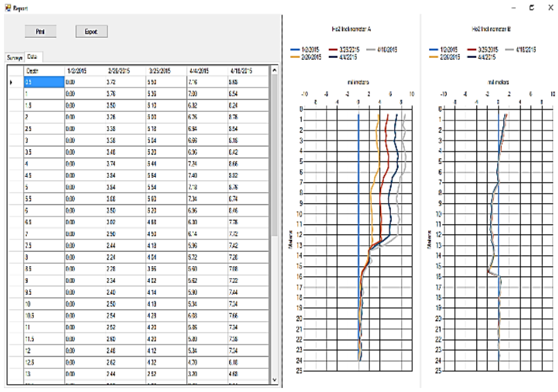

Figure. 13. Display calculation results and comparison chart.

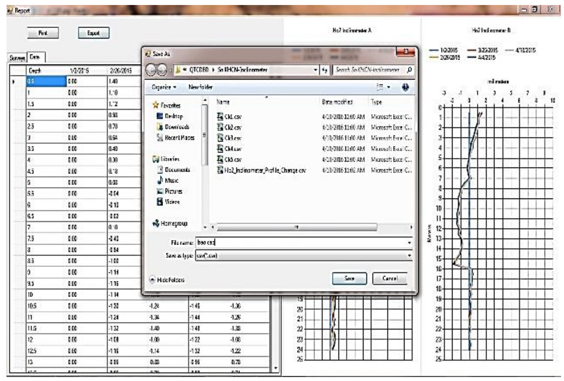

Figure. 14. Export the report to Excel.

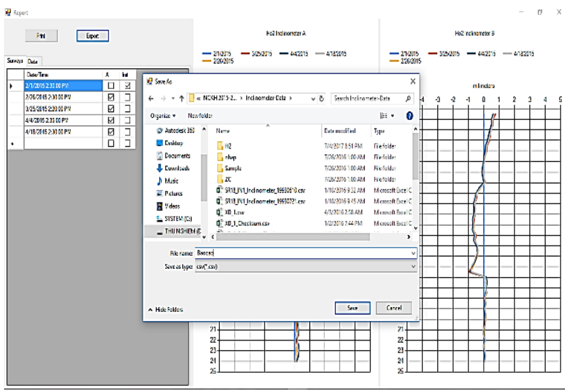

Figure. 15. Editing and printing report.

Step 3: Set up the basic parameters of a measuring cycle (see Figure. 11.)

Step 4: Display data (see Figure. 12.)

Step 5: Show calculation results and comparison chart see Figure. 13.

Step 6: Export the calculated results to the Excel report form see Figure. 14.

Step 7: Editing and printing see Figure. 15.

Displacement at monitoring points Ho2(ICL4) is presented in Table 2.

Table 2. Results of the greatest values of the shifting position monitoring and the corresponding depth of observation positions.

Cycles	Maximum displacement (mm)	Corresponding depth (m)
CK01-CK02	3.88	5.5
CK01-CK03	5.64	4.5
CK01-CK04	7.40	4.5
CK01-CK05	8.82	4.5

This Table 3 showing compared result of five measurement circles using the DigiPro2 software and the InclinometerSoft.

From the data processing results by DigiPro2 and InclinometerSoftware, we have the following observations:

•The results of data processing under the two software are exactly the same in the following parameters: the position has the largest horizontal movement value in each cycle in the two axes A and B, the movement value at position in each cycle in two directions axis A and B (see Table 1, Table 2, Table 3);

•The chart showing the movement of points in each cycle are shown clearly with Inclinometer Soft software (see Figure. 8, Figure.13).

6. Conclusion

- The results of data processing under the two software are exactly the same;

- In comparison to DigiPro2 software, InclinometerSoft software has the following advantages:

+ Can copy and paste in "Add Survey" and "Edit Survey";

+ Import multiple types of data: CSV File (* .csv), ZC File (* .zc), Dgitilt Reader File (* .dux), Gtilt File (* .gtl), RPP File (* .rpp);

+ Save the chart as an image (*.jpg). The chart is exported as .jpg file extension, easier to add to the report;

+ Can change the reference cycle, compare each cycle in separate report;

+ Save the report as a * .csv file;

+English and Vietnamese interface.

- In comparison to DigiPro2 software, InclinometerSoft software has the following disadvantages:

+ Cannot import multiple files at the same time

+ Cannot directly connect to measuring device to exchange data.

Table 3. Compared result of five measurement circles using the DigiPro2 software and the InclinometerSoft.

The maximum movement value in each cycle in direction axis A					
Cycles	DigiPro2		InclinometerSoft		Compare
	Depth	Horizontal movement value max	Depth	Horizontal movement value max	
Cycle 1	5.5	3.88	5.5	3.88	No
Cycle 2	4.5	5.64	4.5	5.64	No
Cycle 3	4.5	7.40	4.5	7.4	No
Cycle 4	4.5	8.82	4.5	8..82	No
Cycle 5	4.5	10.14	4.5	10.14	No
The maximum movement value in each cycle in direction axis B					
Cycles	DigiPro2		InclinometerSoft		Compare
	Depth	Horizontal movement value max	Depth	Horizontal movement value max	
Cycle 1	15.5	-1.78	15.5	-1.78	No
Cycle 2	15.5	-1.92	15.5	-1.92	No
Cycle 3	15.5	-1.72	15.5	-1.72	No
Cycle 4	15.0	-1.66	15.0	-1.66	No
Cycle 5	15.5	-1.84	15.5	-1.84	No

With the above restrictions, we will continue our research to improve this software. In Vietnam, the processing of monitoring data by the sensor still mainly depends on the hardware vendor with a high cost.

Those software products only handles measurement data of a certain measuring line of equipment, cannot handle measurement data of different devices which have different data formats. Meanwhile, users always wished to use a software that can handle measurement data from various types of machines of different firms with different data file formats and low cost. Currently, InclinometerSoft software meets these criteria in the realm of geodetic production in Vietnam. Therefore, InclinometerSoft software can be used to process horizontal displacement captured data from Inclinometer devices in realistic geodetic production in Vietnam.

7. Acknowledgment

We would like to thanks the Project Management "Ha Lam coal mines" had allowed the authors used devices and data. We would like to thanks the research team members of Scientific research at the grassroots level "Measurement and development of data processing program for horizontal shift measurement using Inclinometer".

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