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Building settlement measurement system and reporting on LabVIEW-based soil liquefaction simulator

Bagas Adha Pratama[1], Dian Fajria Zahrah[1], Sulis Setiowati[1,*]

[1]Department of Electrical Engineering, Politeknik Negeri Jakarta, Indonesia
E-mail: sulis.setiowati@pnj.ac.id *
* Corresponding Author

ABSTRACT

A one-axis shaking table soil liquefaction simulator is utilized to study soil behaviour and characteristics, enabling efforts to mitigate liquefaction-indicated soil behaviour. Traditionally, the process of measuring and documenting building settlement, which is a soil variable that indicates liquefaction, involves the use of a pen, paper, and measuring instrument. Therefore, build a measurement system consisting of LVDT displacement sensors and NI cRIO-9025 as the main components, along with LabVIEW software as a novel medium to acquire, process, display, and record measurement data to provide increased measurement accuracy equivalent to traditional instruments. The soil used as material in the test was represented by silica sand with a density percentage of 40-70%. By utilizing the measurement system uses a linear regression scaling method with a sampling time implemented during testing with 100 ms or 10 data/second and descriptive statistical analysis, the soil liquefaction simulator achieves precision with an average measurement error of ±0.89 mm and a reporting operational time efficiency rate of 95.80%. Thus, the accuracy rate of the simulator with the method used in the system is 96.31%.

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1. Introduction

Liquefaction of saturated sandy soils is a phenomenon that has been observed to occur with some frequency in the aftermath of earthquakes. The primary cause of liquefaction can be attributed to a loss of shear strength resulting from an increase in pore water pressure and a reduction in effective stress within the soil. This ultimately gives rise to a state where sandy soils exhibit fluid-like characteristics, leading to a pronounced deformation known as subsidence or ground settlement. The soil liquefaction simulator can be used to model field conditions during and after an earthquake. This allows for observing soil characteristics and behaviour indicating liquefaction after being shaken [1]–[4]. The testing and observation of soil behaviour are expected in the future to identify efforts that can be applied to the field in reducing soil behaviour that indicates liquefaction, one of which is the response to land subsidence indicated by the settlement of buildings [5]–[7]. Typically, the measurement and documenting of soil behaviour response on the simulator is done manually [8]. Due to limitations in conventional methods, accurately measuring soil behaviour can be challenging and may result in errors, including those caused by human error [9].

In order to enhance accuracy and avoid potential errors, the employment of integrated technology for digital measurements and recording is essential. The measurement system comprises detection elements, signal conditioning, processing, and data presentation. Storing the measurement system data in a database can enhance its identification process. The use of databases for data reporting has a strong correlation with their function of storing historical data [10].

Building upon the existing research on liquefaction conducted using a shaking table and incorporating various measurement variables, this study proposes a novel approach. Specifically, it develops a measurement system for building settlement integrated with LabVIEW software as a new way of the data processing methods used in previous studies [1]– [3], [5]– [10]. This approach aims to enhance the precision of data reading and serve as a foundation for future research. By structuring measurement and reporting systems based on function, a comprehensive approach to addressing soil liquefaction can be established. This approach ensures that the necessary data is collected and analyzed to identify potential issues and develop appropriate solutions. With this method, soil liquefaction can be mitigated, thus contributing to the overall safety and stability of structures built on top of the soil [11]. For optimal accuracy in measuring and storing variable data, it is highly recommended to employ the LabVIEW software for both the measurement and reporting systems. This software employs advanced algorithms to ensure precise and reliable readings. By utilizing LabVIEW, users can be confident in the accuracy of their data and reduce the risk of errors or inconsistencies in their results [10]–[15].

This study developed a system for measuring building settlement and reporting on soil liquefaction simulation using linear regression and descriptive statistical analysis methods to process measurement data based on LabVIEW. The system is integrated with LabVIEW software for carrying out data acquisition, processing, and reporting functions on the structure. The system aims to achieve a low error percentage rate, a high level of accuracy, and ease of identification of soil responses.

2. Method

The measurement system for building settlement and reporting in the LabVIEW-based soil liquefaction simulator tool employs a research methodology comprising several stages, beginning with the design of the tool to its realization. This process is depicted in the flowchart in Fig. 1.

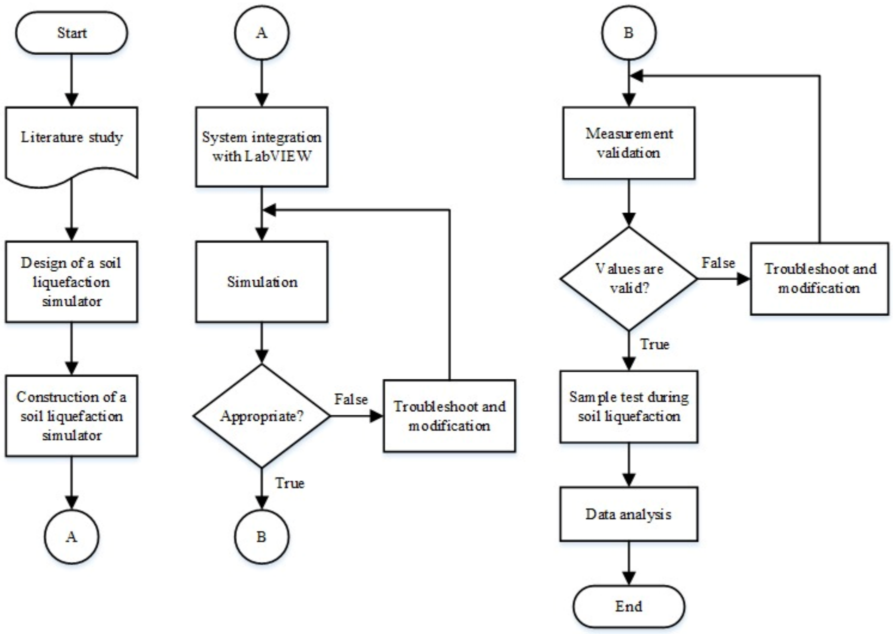

Fig 1. Flowchart of Research Method

The research process is initiated with a literature study, which entails identifying and examining existing knowledge relevant to the topic. The following stage of the process entails the design of both mechanical and program. Subsequently, the researchers proceeded to develop the design, focusing on the mechanics and programming of the soil liquefaction simulator. Then, the simulation of the system is used. if it is not appropriate, then the system will be modified. Furthermore, the sensor validation stage aligns with actual conditions, and if the results are not as expected, the system is modified. Once the validation stage is complete and the results are satisfactory, the sample test stage is initiated, whereby the soil's behaviour during soil liquefaction is observed using the constructed simulator.

The design of the tool in this study consists of designing the hardware system of the soil liquefaction simulator and designing the software system using LabVIEW 2015. The shaking table in this study uses a rigid box model with one-dimensional horizontal motion [3], where the internal dimensions of the test box are length x width x height = 400 x 400 x 600 mm and a maximum load of 150 kg, as shown in Fig. 2a. The wall of the test box is made of acrylic material so that the soil can be seen during the test. Furthermore, there is a sand rainer box designed to release sand into the test box illustrated in Fig. 2b. It is provided with a pulley that connects the chain to the rainer box, so that allows the height of sand falling into the test box to be adjusted.

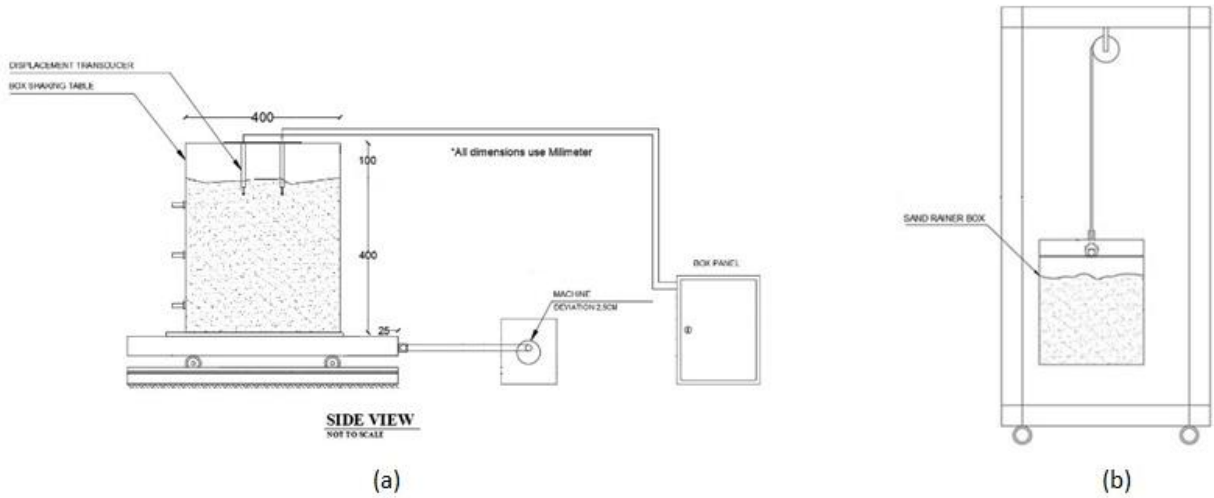

Fig 2. (a) Design of shaking table (b) Design of sand rainer box

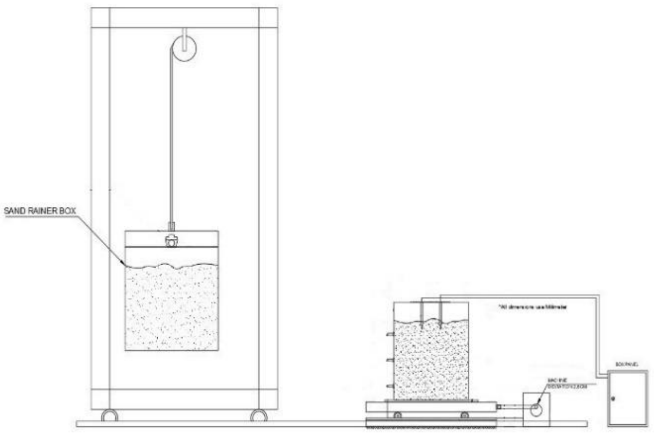

Fig 3. Design of the placement of shaking table and sand rainer box

A soil liquefaction simulator is then formed by positioning the shaking table and sand rainer box as shown in Fig. 3 [4]. The measurement and reporting system implemented in the soil liquefaction simulator consists of three system elements, that is input, process, and output, as shown in Fig. 4.

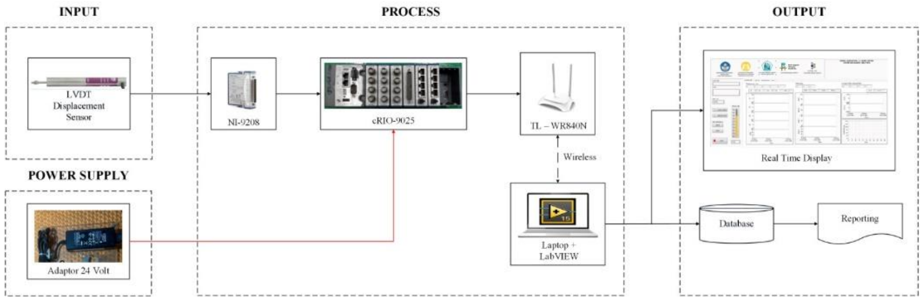

Fig 4. Block Diagram of System

The system block diagram shows that the input block consists of components that fulfil the detection function as an input to the system and that the process block then processes this input. Components in the system input block are four LVDT displacement sensors. The process block comprises a microcontroller that performs data processing functions, specifically NI cRIO-9025. Regarding the process block, the LVDT displacement sensor uses an NI 9208 module as an input device and uses TLWR840N as its wireless communication device. In the system output block, there is a real-time display as a system HMI (Human Machine Interface), a database as a media for storing data and accessing data, reporting to run the process of generating reports in the form of documents containing performance and activity measurement results to inform observers.

The software section has been developed using LabVIEW 2015 as the system programming media for data acquisition, processing, display, and reporting. The system's functionality is depicted through a flow chart, with a workflow diagram designed for the building settlement measurement and reporting system in this research. Based on the flowchart shown in Fig. 5a, the system can be explained in steps, starting with the initialisation of the NI cRIO-9025 input, which is then obtained from the LVDT displacement sensor input. Data processing is then performed using the linear regression scaling method to determine the value of building settlement. Once the variable value is obtained, it is collected in the array to proceed with the decision-making process to determine whether to write zero. If the condition is fulfilled, it will produce a reading when the last condition is, and if the decision to read zero is continued, it will produce data output to zero. When the variable data value changes, a building settlement measurement value will be created and displayed in HMI for data acquisition.

As shown in Fig. 5b, the initial stage involves initialising the controller with LabVIEW. After this, the graph data can be displayed by pressing the "WRITE" and "READ" buttons. To save the data, press the "START WRITE" button which will create a text file formatted as (.txt) containing data, a data header, and write data, which is saved into a database. Press the "STOP WRITE" button to end the data retrieval process. The database data serves as input for the reporting process. Clicking the "REPORT" button initiates the process, assuming that all necessary data has been inputted into the .txt text file. Following computations with descriptive statistical analysis methods, the reporting process generates a PDF report that presents the required values and graphs.

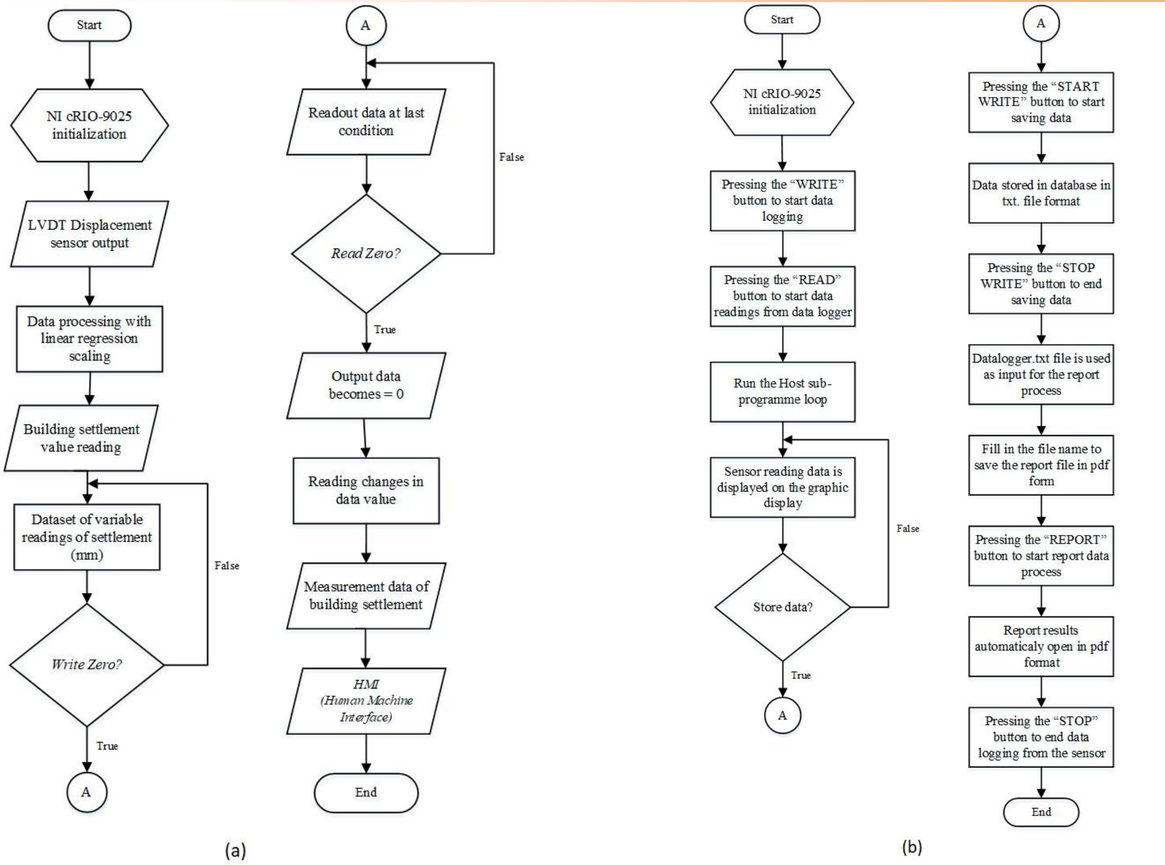

Fig 5. (a) Flowchart of building settlement measurement system (b) Flowchart of reporting system

This implementation stage involves the realisation of the previously designed hardware and software designs. This stage includes the realisation of the hardware design, i.e. the 1-axis shaking table and the sand rainer box.

Fig 6. Integration of Hardware System

Fig. 6 shows the integration of the hardware system with point A, the sand rainer box, and point B, the 1-axis shaking table. Fig. 7 is a software implementation showing the LabVIEW front panel display on the Dashboard tab, which is the system HMI display.

Fig 7. LabVIEW front panel display on dashboard tab

In addition, Fig. 8 shows the LabVIEW front panel view of the Reporting tab, which displays the data reporting function.

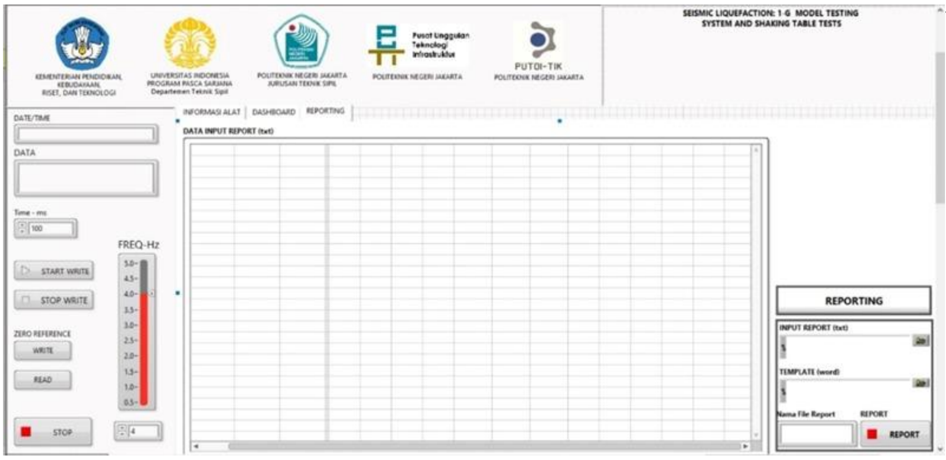

Fig 8. LabVIEW front panel display on reporting tab

3. Results and Discussion

Testing of the building settlement measurement system and reporting of the soil liquefaction simulator tool was undertaken to determine the level of performance of the system implementation. The results and analysis of the system testing are presented below.

The test of the LabVIEW-based building settlement measurement system was conducted on a soil liquefaction simulator at the Soil Laboratory of the Civil Engineering Department of State Polytechnic of Jakarta to determine the measurement results of building settlement during soil liquefaction simulation and to determine the accuracy of the measurement system compared to the reference measurement instrument. The test was carried out by applying a 1 Hz shake to the shaking table using lightweight concrete with dimensions of 19.5 x 19.5 x 10 cm (L x W x H), representing a building. The placement of the LVDT displacement sensor and the building in the test box is shown below.

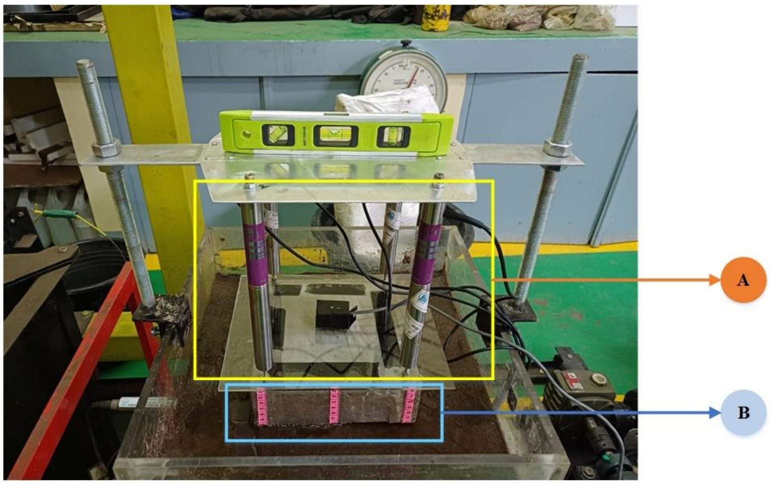

Fig 9. Placement of Sensor LVDT Displacement and Building

Fig. 9 shows the position of the LVDT Displacement sensor marked with point A and the building marked with point B during system testing on the soil liquefaction simulator. Measurement data in this test was obtained with a sampling rate of 10 data/second and the acquisition process was carried out for 5 minutes. The data observed in Table 1 is the average of 10 data at each second. In this test, a 300 mm Mitutoyo Vernier Digital Caliper was used as a reference measurement tool for measuring settlement.

Table 1. Test results data of building settlement measurement system on soil liquefaction simulator

Test at Second	Reference Instrument at LVDT 1 (mm)	LVDT 1 (mm)	Reference Instrument at LVDT 2 (mm)	LVDT 2 (mm)	Reference Instrument at LVDT 3 (mm)	LVDT 3 (mm)	Reference Instrument at LVDT 4 (mm)	LVDT 4 (mm)
1	23.17	24.03	24.57	25.8	20.78	21.39	27.62	28.46
2	23.17	24.04	24.57	25.8	20.78	21.39	27.62	28.46
3	23.17	24.04	24.57	25.8	20.78	21.40	27.62	28.46
4	23.17	24.03	24.57	25.81	20.78	21.39	27.62	28.46
5	23.17	24.04	24.57	25.81	20.78	21.39	27.62	28.46
6	23.17	24.04	24.57	25.81	20.78	21.39	27.62	28.46
7	23.17	24.04	24.57	25.8	20.78	21.39	27.62	28.46
8	23.17	24.03	24.57	25.8	20.78	21.39	27.62	28.46
9	23.17	24.03	24.57	25.81	20.78	21.39	27.62	28.46
10	23.17	24.04	24.57	25.8	20.78	21.39	27.62	28.46
…	…	…	…	…	…	…	…	…
58	23.17	24.04	24.57	25.81	20.78	21.4	27.62	28.46
59	23.17	24.04	24.57	25.81	20.78	21.4	27.62	28.46
60	23.17	24.04	24.57	25.81	20.78	21.4	27.62	28.46

As previously mentioned, the sampling rate applied to the system is 10 data/second, which means that data is stored in the database every 0.1 seconds, resulting in 10 data being entered into the database every 1 second. Testing of this reporting system is carried out under 1 Hz shake conditions with reporting data observed before the shake, during the shake and after the shake. The results of data reporting using LabVIEW software are compared with data processed using Microsoft Excel to determine the efficiency of the use of each software.

Table 2 is the acquisition of data in the database which is known DSPL1 – DSPL4 respectively is the displacement data detected by LVDT sensors 1 – 4 in millimetres (mm).

Table 2. The data before shaking

No.	Time	DSPL1 (mm)	DSPL2 (mm)	DSPL3 (mm)	DSPL4 (mm)
1.	2:39:30 PM	0.01	0	-0.02	0.01
2.	2:39:30 PM	0.01	-0.01	-0.02	-0.01
3.	2:39:30 PM	0.01	-0.01	-0.01	0
4.	2:39:31 PM	0.01	0	-0.02	0
5.	2:39:31 PM	0.01	0	-0.02	0
…	…	…	…	…	…
296.	2:40:00 PM	0.01	0	-0.02	0
297.	2:40:00 PM	0	0	-0.01	-0.01
298.	2:40:00 PM	0	0	0	0
299.	2:40:00 PM	0	0	0	0
300.	2:40:00 PM	0	0	0	0

Based on the data before the shake, the results of descriptive statistical analysis are obtained as reporting data using Microsoft Excel and LabVIEW software as Fig. 10 and Fig. 11.

DSPL1		DSPL2		DSPL3		DSPL4	
Initial Value	0.01	Initial Value	0	Initial Value	-0.02	Initial Value	0.01
End Value	0	End Value	0	End Value	0	End Value	0
Settlement Value	0.01	Settlement Value	0	Settlement Value	-0.02	Settlement Value	0.01
Mean	0.00415	Mean	-0.0004	Mean	-0.0109	Mean	0.00204
Standard of Deviation	0.00552	Standard of Deviation	0.00574	Standard of Deviation	0.00836	Standard of Deviation	0.00488
Minimum	-0.01	Minimum	-0.02	Minimum	-0.03	Minimum	-0.01
Maximum	0.02	Maximum	0.02	Maximum	0.01	Maximum	0.01

Fig 10. Pre-shake results reporting using Microsoft Excel

DSPL 1 (mm)	DSPL 2 (mm)	DSPL 3 (mm)	DSPL 4 (mm)
Initial Value : 0.01	Initial Value : -0.00	Initial Value : -0.02	Initial Value : 0.01
End Value : 0.00	End Value : -0.00	End Value : -0.00	End Value : 0.00
Settlement Value : 0.01	Settlement Value : 0.00	Settlement Value : -0.02	Settlement Value : 0.01
Mean : 0.00	Mean : -0.00	Mean : -0.01	Mean : 0.00
Standard of Deviation : 0.01	Standard of Deviation : 0.01	Standard of Deviation : 0.01	Standard of Deviation : 0.00
Minimum : -0.01	Minimum : -0.02	Minimum : -0.03	Minimum : -0.01
Maximum : 0.02	Maximum : 0.02	Maximum : 0.01	Maximum : 0.01

Fig 11. Pre-shake results reporting using LabVIEW

When testing the reporting system before this shake using LabVIEW, it takes 13.98 seconds to get the analysed data as shown in Fig. 11. Meanwhile, using Microsoft Excel manually with the statistical descriptive data analysis tools, it takes 7 minutes 32 seconds or 452 seconds to get the analysed data as shown in Fig. 10.

Table 3 shows the data during shakes obtained from the database.

Table 3. The data during shaking

No.	Time	DSPL1 (mm)	DSPL2 (mm)	DSPL3 (mm)	DSPL4 (mm)
1.	2:40:07 PM	0	0	-0.02	0.01
2.	2:40:07 PM	0	-0.01	-0.01	0
3.	2:40:07 PM	0	0	0	0
4.	2:40:07 PM	0.01	0	-0.01	0.01
5.	2:40:07 PM	0	-0.01	-0.02	0
…	…	…	…	…	…
596.	2:41:06 PM	-0.2	0.01	-0.01	-0.16
597.	2:41:06 PM	-0.19	0	-0.03	-0.19
598.	2:41:06 PM	-0.2	0	-0.01	-0.17
599.	2:41:06 PM	-0.2	-0.01	0	-0.18
600.	2:41:06 PM	-0.2	0	-0.02	-0.17

Based on the data during the shake, the results of descriptive statistical analysis are obtained as reporting data using Microsoft Excel and LabVIEW software as Fig. 12 and Fig. 13.

DSPL1		DSPL2		DSPL3		DSPL4	
Initial Value	0	Initial Value	0	Initial Value	-0.02	Initial Value	-0.01
End Value	-0.21	End Value	-0.03	End Value	-0.01	End Value	-0.18
Settlement Value	0.21	Settlement Value	0.03	Settlement Value	-0.01	Settlement Value	-0.017
Mean	-0.12507	Mean	-0.00472	Mean	-0.01285	Mean	-0.09748
Standard of Deviation	0.05589	Standard of Deviation	0.00656	Standard of Deviation	0.00676	Standard of Deviation	0.05387
Minimum	-0.22	Minimum	-0.03	Minimum	-0.03	Minimum	-0.019
Maximum	0.01	Maximum	0.01	Maximum	0.01	Maximum	0.02

Fig 12. During shake results reporting using Microsoft Excel

DSPL 1 (mm)	DSPL 2 (mm)	DSPL 3 (mm)	DSPL 4 (mm)
Initial Value : 0.01	Initial Value : 0.00	Initial Value : -0.02	Initial Value :- 0.01
End Value : -0.21	End Value : -0.03	End Value : -0.01	End Value : -0.18
Settlement Value : 0.21	Settlement Value : 0.03	Settlement Value : 0.01	Settlement Value : 0.17
Mean : -0.13	Mean : -0.00	Mean : -0.01	Mean : -0.10
Standard of Deviation : 0.06	Standard of Deviation : 0.01	Standard of Deviation : 0.01	Standard of Deviation : 0.05
Minimum : -0.22	Minimum : -0.03	Minimum : -0.03	Minimum : -0.19
Maximum : 0.01	Maximum : 0.01	Maximum : 0.01	Maximum : 0.02

Fig 13. During shake results reporting using LabVIEW

When testing the reporting system using this shake by LabVIEW it takes 14.2 seconds to get the analysis result data as shown in Fig. 13. When using Microsoft Excel manually by the statistical descriptive data analysis tools, it takes 7 minutes 36 seconds or 456 seconds to get the analysis result data as shown in Fig. 12.

Table 4 shows the data during shakes obtained from the database.

Table 4. The data after shaking

No.	Time	DSPL1 (mm)	DSPL2 (mm)	DSPL3 (mm)	DSPL4 (mm)
1.	2:41:12 PM	-0.2	-0.01	-0.01	-0.18
2.	2:41:12 PM	-0.2	0	-0.01	-0.18
3.	2:41:12 PM	-0.21	0	-0.01	-0.17
4.	2:41:12 PM	-0.2	-0.01	-0.01	-0.18
5.	2:41:12 PM	-0.21	0	-0.01	-0.18
…	…	…	…	…	…
2996.	2:46:11 AM	-0.2	0.01	-0.01	-0.16
2997.	2:46:11 AM	-0.19	0	-0.03	-0.19
2998.	2:46:11 AM	-0.2	0	-0.01	-0.17
2999.	2:46:11 AM	-0.2	-0.01	0	-0.18
3000.	2:46:11 AM	-0.2	0	-0.02	-0.17

Based on the data after the shake, the results of descriptive statistical analysis are obtained as reporting data using Microsoft Excel and LabVIEW software Fig. 14 and fig. 15.

DSPL1	
Initial Value	-0.2
End Value	-0.21
Settlement Value	0.01
Mean	-0.20578
Standard of Deviation	0.05396
Minimum	-0.22
Maximum	-0.19

DSPL2	
Initial Value	-0.01
End Value	-0.01
Settlement Value	0
Mean	-0.00405
Standard of Deviation	0.00643
Minimum	-0.02
Maximum	0.03

DSPL3	
Initial Value	-0.01
End Value	-0.01
Settlement Value	0
Mean	-0.01153
Standard of Deviation	0.00654
Minimum	-0.03
Maximum	0.01

DSPL4	
Initial Value	-0.18
End Value	-0.17
Settlement Value	-0.01
Mean	-0.17798
Standard of Deviation	0.00602
Minimum	-0.2
Maximum	-0.16

Fig 14. After shake results reporting using Microsoft Excel

DSPL 1 (mm)	DSPL 2 (mm)	DSPL 3 (mm)	DSPL 4 (mm)
Initial Value : -0.20	Initial Value : -0.01	Initial Value : -0.01	Initial Value :- 0.18
End Value : -0.21	End Value : -0.01	End Value : -0.01	End Value : -0.17
Settlement Value : 0.01	Settlement Value : 0.00	Settlement Value : 0.00	Settlement Value : 0.11
Mean : -0.21	Mean : -0.00	Mean : -0.01	Mean : -0.18
Standard of Deviation : 0.01	Standard of Deviation : 0.01	Standard of Deviation : 0.01	Standard of Deviation : 0.01
Minimum : -0.22	Minimum : -0.02	Minimum : -0.03	Minimum : -0.20
Maximum : -0.19	Maximum : 0.03	Maximum : 0.01	Maximum : -0.16

Fig 15. After shake results reporting using LabVIEW

When testing the reporting system after this shake using LabVIEW, it takes 28.69 seconds to get the analysed data as shown in Fig. 15. Meanwhile, using Microsoft Excel manually with the statistical descriptive data analysis tools takes 7 minutes 55 seconds or 475 seconds to get the analysed data as shown in Fig. 14.

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Based on the data in Table 1, the measurement graph of each sensor is obtained in Fig. 16.

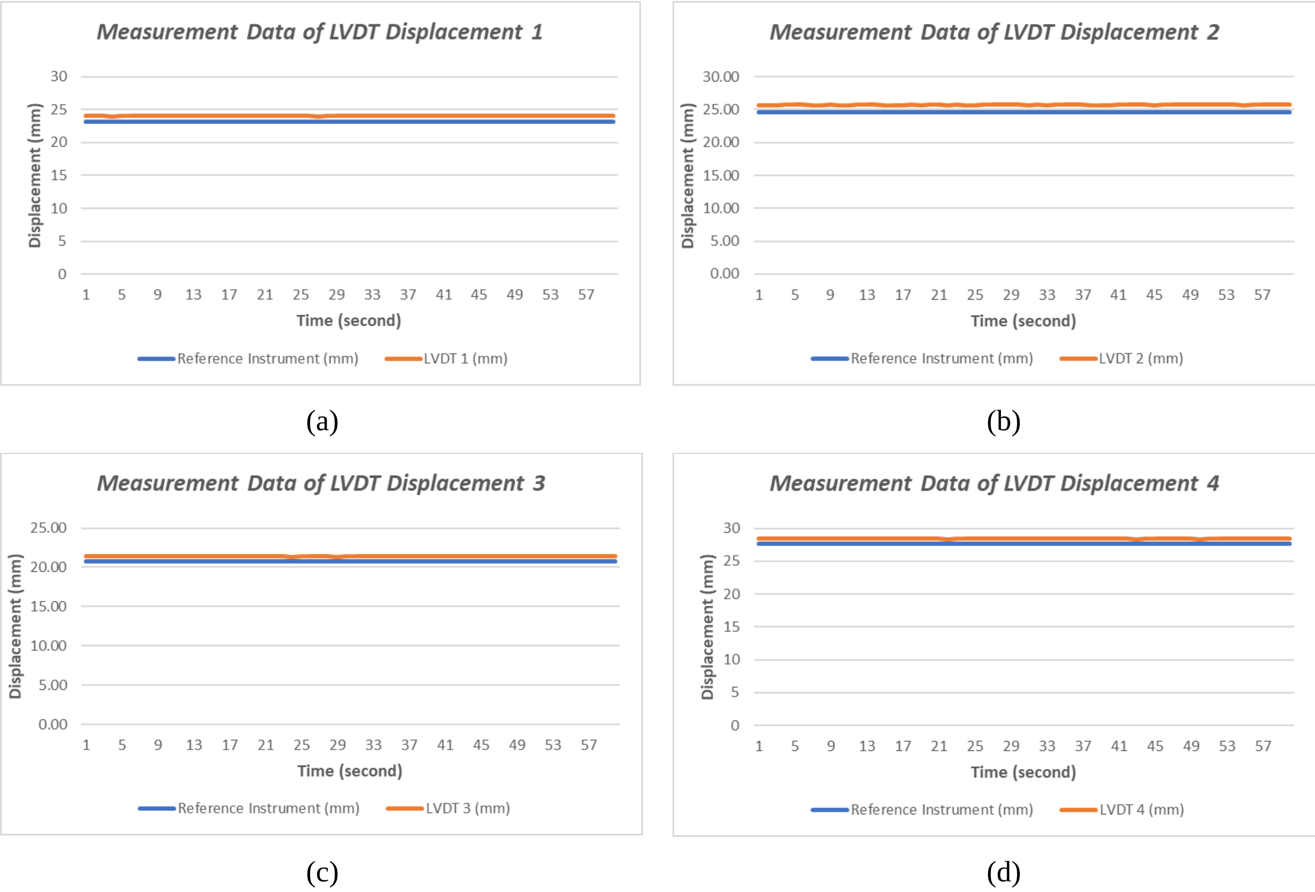

Fig 16. Measurement Data of LVDT Displacement Sensor

Based on the graphical data in Fig. 16a – d, the accuracy level of each sensor was obtained based on the percentage error of the building settlement measurement during the test on the soil liquefaction simulator, as shown in Table 5.

Table 5. Building settlement measurement system test data analysis results for soil liquefaction simulator

Average of			
Measurement Deviation of LVDT 1 (mm)	***Measurement Error of LVDT 1***	***Measurement Deviation of LVDT 2 (mm)***	***Measurement Error of LVDT 2***
0.87	3.74%	1.24	5.03%
Average of			
Measurement Deviation of LVDT 3 (mm)	***Measurement Error of LVDT 3***	***Measurement Deviation of LVDT 4 (mm)***	***Measurement Error of LVDT 4***
0.61	2.94%	0.84	3.04%

Table 6. Accuracy level of the building settlement measurement system on the soil liquefaction simulator for each sensor

Accuracy Rate of			
LVDT 1	***LVDT 2***	***LVDT 3***	***LVDT 4***
96.26%	94.97%	97.06%	96.96%

The percentage of measurement error of the settlement by the LVDT Displacement 1-4 sensors is a reference in determining the level of accuracy achieved by the system to show the level of system performance. Based on the measurement error percentage values shown in Table 5, the accuracy level of each sensor can be determined as shown in Table 6. Thus, if the average accuracy of the four sensors is calculated, it can be said that the building settlement measurement system on the LabVIEW-based soil liquefaction simulator has an accuracy rate of 96.31%.

The factor that causes the measurement error of the settlement of the LVDT displacement sensor based on the test on the soil liquefaction simulator is human error in pulling the finger hook when moving the slider on the measurement of the vernier calliper to obtain a reference value from another measuring instrument. The human error occurs because the researcher has difficulty in aligning the vernier calliper due to the measurement area blocked by the sensor holder plate, so the deviation rate between the reference measurement results and the sensor in the system becomes larger considering the accuracy of the vernier calliper reading of ± 0.01 mm.

The acquisition of report data using both Microsoft Excel and LabVIEW is compared to provide information about the level of time efficiency of using the LabVIEW-based report system through calculations using Equation 1.

$$\%\ \text{reporting time efficiency} = \frac{\text{Operating time of A software} - \text{Operating time of B software}}{\text{Operating time of A software}} \times 100\% \quad (1)$$

Based on the test results that is, observations before, during and after shakes, the data reporting of the analysis results between Microsoft Excel and LabVIEW has no difference in value or error = 0%. Table 7 shows a comparison of the time taken to report the test data using Microsoft Excel and LabVIEW so that the level of efficiency of the reporting time can be obtained from the comparison.

Table 7. Comparison of percentage of reporting time efficiency

Observation	**Time Required for Reporting**		**Percentage of Reporting Time Efficiency**
	Microsoft Excel (second)	**LabVIEW (second)**	
Before shaking	452	13.98	96.9%
During shaking	456	14.2	96.8%
After shaking	475	28.69	93.9%

Table 7 shows that using the LabVIEW-based reporting system takes less time to report the results of test data analysis than using Microsoft Excel. Thus, based on the percentage of reporting time efficiency from three observations, that is, before, during and after shakes using LabVIEW software, the average level of reporting time efficiency is 95.8%.

4. Conclusion

A building settlement measurement and reporting system for a LabVIEW-based soil liquefaction simulator was developed using LabVIEW programming to achieve the goals of easy measurement and recording, low measurement error, and high accuracy. The measurement data processing and reporting used the linear regression scaling method and descriptive statistical analysis implemented by programming LabVIEW FPGA for high-speed and reliable processing. The measurement system built, when compared between the verified manual measuring instrument and the LVDT displacement sensor in measuring building settlement in the soil liquefaction simulator, obtained an average measurement difference of ± 0.89 millimetres with an average accuracy rate of 96.31% in measuring building settlement during testing on the soil liquefaction simulator when given a 1 Hz shake. The LabVIEW-based reporting system successfully created a report document in PDF format by displaying the value of sensor readings, graphs, and statistical analysis data. The data in the report document using LabVIEW produces graphs with accurate values because there is no difference or error when compared to the results of data processing using Microsoft Excel, and the report operation time shows that the use of LabVIEW is 95.8% more efficient than using Microsoft Excel manually.

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