Automation of processing the results of Laboratory studies of frozen and thawed soils soil research

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***Abstract*—The work was carried out to create a computational system based on interconnected Excel workbooks for automating the processing of laboratory test data for frozen and thawed soils. An analysis was conducted of the software used in engineering surveys, which revealed their advantages and disadvantages, as well as the key requirements for the new system. Several factors negatively affecting or complicating workflows were identified: high labor intensity of manual operations, the risk of data entry errors, and low information processing speed. Based on the findings, comparisons were made between existing software solutions and the developed system, allowing for the identification of optimal automation approaches. As a result, an integrated automated system was developed, significantly improving the accuracy and speed of laboratory data processing while reducing the likelihood of errors in manual entry and calculations. The article details the key stages of system development, its structure, functionality, and user interface. Testing was performed using real laboratory research data, confirming the effectiveness of the proposed approach. The results demonstrate significant advantages of implementing the automated system in practice, enhancing the quality, reliability, and efficiency of frozen and thawed soil studies. In the future, the system's functionality is expected to be expanded for comprehensive data analysis.**

***Keywords*—Automation, calculation of laboratory data, frozen and thawed soils, laboratory studies, soil research.**

I. Introduction

Digital automation is currently a key discipline in optimizing workflows in all areas and spheres of engineering and geological surveys, including soil research laboratories.

Understanding the physical and mechanical properties of soils is critical for design and construction. Properties such as moisture, density, porosity, compressive and shear strength allow not only to build geological cross-sections of the area, but also to determine the stability of soils under load. This helps in selecting appropriate construction technologies and soil stabilization methods to avoid deformation and collapse of buildings, roads, and other filed structures.

It is important not only to correctly conduct the necessary exploration, but also to quickly and correctly process all the findings. In the process of estimating the results of laboratory tests of the physical and mechanical properties of soils, there is a number of factors that affect the results of the entire work effort: first, it is the abundance of routine processes, and second, the human factor and associated errors. Eliminating these factors by automating the computations would speed up the generation of correct results in a short time.

The idea of automation has been developing for several years and now there is a number of software tools on the market designed for work in the field of laboratory soil research, each having its own advantages and disadvantages [1].

At the moment, the soil research laboratory uses the KT Geologist software package developed by Yunis-Yug company to process test results [2].

During the study, a number of features were identified that increase the data processing time:

II. Issues with importing data from Excel files

Each of the files containing the data to be imported (in our case, the register with the well number, depth, and soil description) must be pre-treated in advance by creating a link between the table column and the KT Geologist parameter using the XSD diagram. This diagram is created through a separate menu directly in a KT Geologist project. The saved diagram is imported into the Excel workbook as an XML map, and each XML element is compared with the column containing the necessary data. The next step is to export the resulting spreadsheet as a .xml file as a ready-made diagram. After this step, to load data from Excel files, one will need to use this algorithm, which seems simple enough. However, there is a number of difficulties.

The spreadsheet data for forming and exporting the diagram are to be performed each time for each individual register with tabular data on samples, which requires a lot of time.

For successful import of the laboratory number, well, sampling depth, and sample type, the original spreadsheet must be brought to a certain form:

The cells format in the spreadsheet is important. For example, if the sampling depth contains a period instead of a comma, which forms a fractional number, the program will return an error during the import process.

The sampling depth must be filled in two separate columns (“from” and “to” or “top” and “bottom”). Such a division introduces significant restrictions for those program users who have registers with a single sampling depth value.

The soil structure must be coded as “TRUE” – for a

Manuscript received May 20, 2025.

broken structure, or “FALSE” – for a monolith. Similar coding is used for the soil condition (“TRUE” - frozen, “FALSE” - thawed).

In this case, the user has the following choice: change the company’s registry template or spend time editing the necessary spreadsheets each time to quickly import all the data into the program. Certain difficulties are also caused by the fact that each XML element is encoded under a specific name which must be periodically checked against the reference book in the user manual when preparing the spreadsheet for import.

Due to the above issues, importing data from Excel files has a high entry threshold. In practice, the users most often use manual data entry.

III. The software includes a large number of modules that are not used for their intended purpose

The software package includes modules for joint work of field, office, and laboratory departments. Provided that all departments work in this software, this is a great advantage. However, in many cases, just like in our company, each department uses its own local computing tables and files in their work processes. In this case, all these modules in the navigation menu make the interface heavier and create visual noise.

IV. Issues with simultaneous connection of several users to one working document

In the course of work in this software, it was found that when two or more people connect to a single file together, as well as during their further joint work, every now and then problems arise during data saving. When one user saves a document, these changes might not apply for the other user. Most often, this happens when entering particle density and soil temperature data.

V. Unsafe storage of data from all modules in one project file

A project with the geol extension is created when working in the program, and, due to its wide capabilities, it can store field, laboratory, and office studies data. Therefore, if this file is damaged, all this data will be lost, and a large amount of work will have to be restored from scratch.

The financial side should not be denied either - for several people to work simultaneously in a work file, two or more license keys must be purchased.

In this regard, we decided to implement our own computing system based on Excel linked books, and also compare it with the existing KT Geologist software.

Excel was selected as the basis due to its versatility and accessibility. It is installed on each office computer and has excellent compatibility with other tables used in the work. Thus, it allowed to cover in detail all the laboratory processes: from the acceptance of soil samples to results processing. All modules of the complex are created using macros. The structure of the complex is shown in Figure 1.

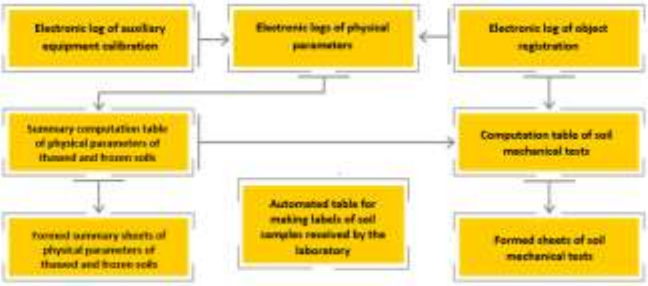

Fig. 1. Dependence diagram of modules of the implemented complex

VI. The example of a sequence of work processes

The operation of this diagram can be most easily explained using the example of a sequence of work processes of a soil laboratory which use the electronic logs.

A. *Electronic Log of Auxiliary Equipment Calibration*

Let us start with the auxiliary module of the system which stores data on all auxiliary equipment used in laboratory research and which must be calibrated. These are pycnometers, aluminum weighing bottles, field cutting rings, rings for testing frozen soils, etc. All of them are weighed and the measured mass is entered into the log, which is then automatically entered into all computation modules of the system and determined by the equipment serial number. Calibration is performed at certain intervals. Changes in the equipment mass will be automatically applied in all modules of the system.

B. *Electronic Log of Objects Registration*

Initially, the laboratory receives soil samples collected during drilling. For efficient management, recording of the dates of sample receipt, and further tracking of the objects issue dates, the implemented system uses an electronic log of objects, which is shown in Figure 2. The object code and the object name (according to the register) are entered into the log, a laboratory number is assigned; the object receipt date, the number of received samples for each sample type (thawed monolith, frozen monolith, disturbed structure sample), and the work order receipt date are entered.

The log also contains hyperlinks to the register containing all the information on the received samples, and a document with data on all discrepancies (Fig. 3). This ensures convenient navigation between files associated with the object, bypassing a complex system of a large number of folders and files. Other modules of the implemented system refer to this log to obtain data on the laboratory number, object code, etc.

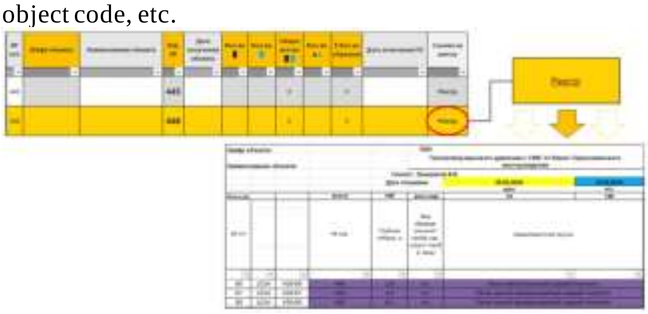

Fig. 2. Electronic log of objects registration

Fig. 3. Electronic log of non-conformities during registration of objects

C. Automated Spreadsheet for Generating Labels when Registering Received Samples

After the soil samples have been accepted, the registration process begins. Each sample from the register is assigned its own laboratory number, and special labels are generated, printed out, cut and put into the soil sample package. Before, electronic tables were compiled manually by the "copy-paste" method, now a separate module is responsible for this.

The interface of the system modules is made according to a unified pattern. It is implemented in the form of colored buttons: "Select register", "Apply loaded register", "New sheet". Thus, data loading is done in three mouse clicks (Fig. 4):

Fig. 4. Buttons of the system modules interface

1) The yellow button "Select register" opens a pop-up window where you need to select a table with the desired register.
2) Clicking the orange button "Apply loaded register" starts the process of integrating data from the selected file. It happens automatically and the process results in filling the cells with data from the register.
3) The green button "New sheet" copies the empty template to a new sheet to generate the next log or table.

The table for generating labels for registration is shown in Figure 5.

Fig. 5. Table for creating labels for sample registration

The interface has an additional blue button that splits labels by sample type (separately thawed monoliths, frozen monoliths, disturbed structure samples) and saves them as a separate file with a specified name containing the object code and laboratory number, completely ready for printing and further cutting.

Ready-made labels are available as a result (Fig. 6).

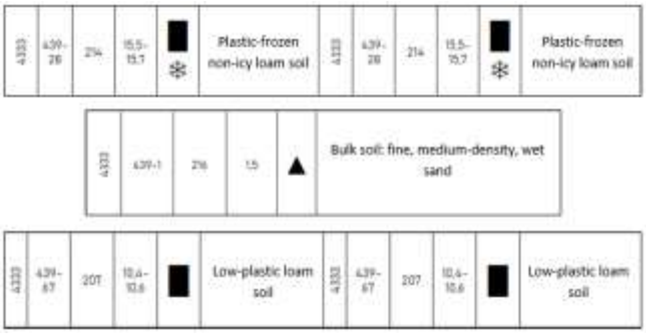

Fig. 6. Labels generated for registering soil samples

D. System of Electronic Logs for Determining the Physical Properties of Soils

After all soil samples have been assigned a laboratory number and a label has been placed inside the sample, the physical properties of the soils are measured under laboratory conditions. The next module includes a number of automated logs in which test data are entered and parameters are automatically calculated.

At present, the logs for determining the following properties have been implemented:

- Moisture content of dispersed soils [3]
- Moisture content of organic soil and peat decomposition degree [3]–[4]
- Moisture at liquid limit / rolling out limit [3]
- Particle size distribution of sandy soils by the sieve analysis method [5]
- Particle size distribution of clayey soils by the areometric method [5]
- Soil density [3]
- Relative content of organic matter and ash content [6,7].

Examples of logs are shown in Figures 7 – 8.

Fig. 7. Electronic log for determining soil moisture

Fig. 8. Electronic log for determining soil density

The complex is under development now and there is a plan to implement logs for determining particle density, soil salinity, specific electrical resistivity, and other tests carried out in the laboratory.

Data import from the register is implemented in three clicks according to the scheme described above. The cell with the test date is determined as today and is set by a special button; after clicking the button, on the day of entering data into the log, the date will not change (Fig. 9).

Fig. 9. Test date button

There are also additional buttons for converting all the log cells from formula to values format and back (Fig. 10).

Fig. 10. Buttons for converting cells from formula to values format and back

When working together on a single object, having separate logs for each type of test allows a separate worker to be assigned to one log and enter data without interfering with other workers. Also, several separate logs will help avoid the problem that can arise when one of the files is damaged, since it is much easier to restore data on one type of test than on all the information at once if they were stored in a single file. Breaking down into test logs allows one to store test data in a structured manner and have access to it at any time.

E. *Summary Calculation Sheet*

After all tests have been carried out, the data processing stage begins which is performed by the following module of the automated system.

The summary calculation sheet is a table that compiles the results of all tests and is intended to deliver the results to the office department (Fig. 11). This module has the largest number of links with all the described modules of the system and is the most important one. In the interface, in addition to the three described buttons “Select register”, “Apply loaded register”, and “New sheet”, there is a “Hide/Show” button.

It is intended for the columns of mechanical test results. This simplifies navigation through the table. There are buttons for generating a final summary sheet separately for thawed and frozen soils. Clicking them starts the process of bringing the calculation sheet to the format approved in the company and saves these summary sheets as separate files. The sheet columns are color-divided by indicators (blue shows frozen soils, orange shows thawed soils).

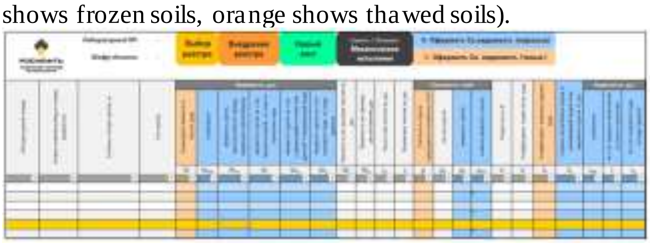

Fig. 11. Summary payroll

For ease of navigation through the table, when selecting the desired cell, the entire row is highlighted in color. Empty cells, obviously incorrect values, for example, the degree of filling of frozen soil pores with ice and unfrozen water Srf>1, are marked in orange, and any negative values are marked in red (Fig. 12).

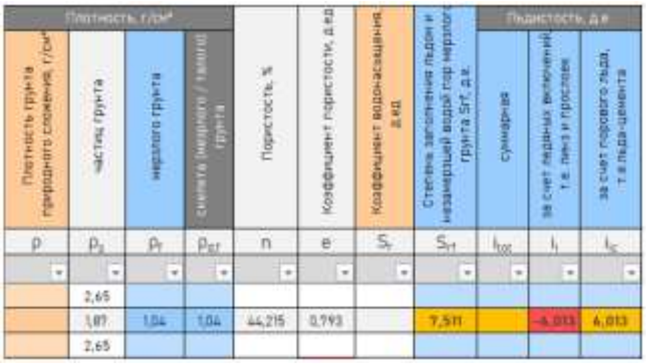

Fig. 12. Color marking of incorrect and/or erroneous values

F. *Comparison of KT Geologist and the Developed Complex*

The objective of the comparative analysis of the operation of the ready-made software with the developed complex is to compare the data processing speed, in particular the speed and ease of integration of the initial data from Excel files.

For this purpose, a register was taken containing 100 soil samples, including 25 samples with disturbed structure and 75 monolith samples. The number of frozen soils is 77 pcs., thawed soils - 23 pcs.

In total, importing data, entering the tests results in the corresponding columns, and their processing in the KT Geologist software took 2 hours 54 minutes. The developed complex handled the same task in 1 hour 38 minutes.

Detailed time costs are given in Table I.

Table I. Stage-by-stage time costs for importing, entering, and processing the data in the computing complexes under consideration.

Process	Run time	
	KT Geologist	Developed complex
Data import	12 min	5 min
Entering test data	1 h 35 min	1 h 03 min
Processing results	1 h 07 min	30 min

G. *Other Advantages of the System*

The financial issue also plays a major role. The complex development does not require any additional financial costs, since a licensed version of Microsoft Office with the Excel package is available on each work station and is used in a large number of tasks. While, at the time of this study, according to information from the official website of Yunis-Yug [1], the cost of one license key for the KT Engineering Geology with integrated KT Geologist for one year is 355,300.00 rubles. For full-fledged work of laboratory workers with the ability to simultaneously work together in several projects, this software will require 6 keys (equivalent to 2,131,800.00 rubles).

H. *Disadvantages of the System*

The following disadvantages should be noted:

- Technical support of the system after the end of development will be ensured by the company (process automation department) and the laboratory staff
- It was noted that when working with large data volumes in extreme testing mode, long-time uploading drags of the Excel program occur after activating macros with a number of lines greater than 1000
- For the correct operation of the entire system, it is necessary to adhere to a strict structure in the naming of file

names, Excel worksheets, and folder names used in the implemented system

• Like any software package, it has a certain entry threshold (requires training).

VII. Results

The paper described a number of issues related to the existing software applied to processing the results of laboratory studies of soil and the principle of operation of the automated information system under development. Excel-based (with the use of macros) digital logs on various tests, secondary modules for registration of soil samples, and micromanagement of the laboratory, as well as the main module for processing laboratory studies and generating summary sheets were created. Based on the results of the study, a comparative analysis of this system with the KT Geologist software package was carried out in the field of information processing rate, which proved the high performance of the introduced system.

VIII. Conclusion

The software solution implemented within this study somewhat changes the approach to the development of software for engineering and geological surveys with a focus on laboratory soil studies. Shifting away from versatility in favor of a detailed workflow allows one to cover a larger number of work tasks and optimize routine processes that require a lot of time. This software package helps to improve the rate of processing the results of laboratory tests of soils and their assembly into summary sheets. The plasticity of the system structure and interface allows for the further implementation of additional modules for the needs of the laboratory, and structured storage of test data in the future will allow to create a database supporting comprehensive studies of soil features within specific work sites.

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