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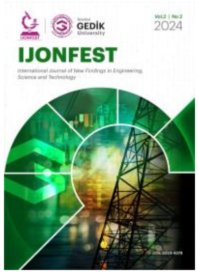

Developing Soil Liquefaction Analysis Program created on Visual Basic Analysis in MS Excel based on the 2018 Turkish Seismic Code

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Abstract

The rapid increase in the world's population, the desire to revise old structures or to need new structures, and the decrease in usable areas in some big cities lead engineers to examine ground conditions more frequently. Due to Turkey's location and geological structure, earthquake occurrences are quite high. The loss of life and property, which has increased with the earthquakes that have occurred in our country (Turkey) in recent years, has been examined and it has been seen that this situation is related to the ground factor rather than the superstructure design inadequacies. In this sense, the main goal of investors is to optimize the profit to be obtained by providing the aesthetics of the superstructure, comfort, and interior quality in building projects such as residences and offices. For this reason, geotechnical design is becoming a discipline that needs to be solved most economically. Starting the investment without paying due attention to the seismicity of the ground in the investment budgets, when the risk of liquefaction in the ground may come to the fore, it is possible to avoid unaccounted ground improvement methods, so new buildings with the risk of soil liquefaction are added to the unsafe old building stock. With the 2018 Seismic Code in Turkey, liquefaction on the ground and different problems that occur on the ground have been examined in more detail. Within the scope of this study, it was focused on getting faster results with faster and on-site determinations of the liquefaction situation on the ground, thanks to the Visual Basic application program prepared in Excel. In this sense, with the program prepared as the aim of the study, it is aimed to enable the construction of the soil liquefaction analysis to be made quickly and with less cost and to start the construction with a realistic budget and structural models. The program continuously increases its sensitivity and accuracy with additional inputs. This allows geotechnical engineers to achieve faster and earlier results.

Keywords:Earthquake; Soil Liquefaction; TBDY; 2018 Turkish Seismic Code Regulation.

1. INTRODUCTION

The energy that occurs as a result of sudden breaks in the earth's crust and spreads by seismic waves is called an earthquake. Earthquakes are disasters that negatively affect life in nature. It is possible to see the negative effects of the earthquake in all areas such as superstructure, infrastructure, and soil-bearing capacity losses [01]. Although it is in the same region, it can be thought that one of the reasons for the different damages in the structures is the failure

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to consider the structure-soil interaction. It has been observed that some of the damages observed in the structures after the earthquakes in our country are due to soil liquefaction.

During an earthquake, when the groundwater level is high, with the increase of pore water pressure of saturated non-cohesive soils under static and dynamic loads, the phenomenon called "liquefaction" occurs by acting like a liquid. At the end of the liquefaction event, there is a loss of strength in non-cohesive soils, and as a result, the soils lose their bearing capacity [2]. In particular, irreversible damages may occur in the superstructure as the ground loses its strength and becomes unable to carry the loads coming from the superstructure. The same negative effects can be seen in infrastructure systems.

With the prepared study, the liquefaction problem on the ground is detected early by using different regulations and methods, and more precise results are obtained by early intervention with a Visual Basic-based program, the data is obtained as a result of on-site investigations and laboratory tests are prepared on MS Excel. The results were obtained by using different methodologies to examine the differences in the liquefaction status of the ground and the shear wave velocity of the earthquake code prepared in the 2018 Turkey Building Seismic Code (TSC) used in our country and the earthquake regulation prepared in the TSC-2007. In this study, it is aimed to intervene in the problem on the ground early and reduce or completely eliminate the risk.

The frequent occurrence of earthquakes in Turkey, coupled with the high risk of soil liquefaction, has underscored the necessity for advanced geotechnical design. Despite the adoption of the 2018 Turkey Building Seismic Code (TSC), there is a pressing need for a cost-effective, efficient, and accurate method to assess soil liquefaction risk during the early stages of construction projects. Current practices often overlook the critical interaction between structure and soil, leading to significant damage during seismic events. As a research gap, this study aims to bridge this gap by developing a Visual Basic application within MS Excel that facilitates rapid and precise soil liquefaction analysis, thereby enabling geotechnical engineers to make informed decisions and implement timely soil improvement methods. However, the study does not compare this new method with other existing analysis techniques, which represents a limitation that future research should address.

2. METHODOLOGY

2.1 Regulations and Calculation Procedures

Turkey's current Seismic Code is the Building Earthquake Code 2018 published on 31.12.2018. It contains precise information about what should be considered for the superstructure or infrastructure to be built in a sequential and phased manner [3]. TSC-2018 provides much more comprehensive and clear information by creating a separate section on the liquefaction problem in the research.

2.2.1. *Liquefaction Analysis According to the 2018 Turkish Seismic Code*

Along with the regulation that considers every region as an earthquake zone, it is determined whether there is liquefaction in the ground as a result of a comprehensive ground examination with the analyzes obtained as a result of laboratory and experiments in the regions where soil groups belonging to the soil class “ZD, ZE, ZF” are located 20 m from the ground. should be done. Numerical liquefaction analysis is performed with the following steps.Moment magnitude (Mw) values of possible earthquakes produced by faults should be calculated.

$$Mw = a + b \log (SRL) \tag{1}$$

SRL: The length of the expected surface rupture (km), coefficients a and b: Depends on the type of fault.

The a and b coefficients in the equation giving the scenario earthquake magnitude with the fault segment approach is given in Table 1.

Table 1. The a and b coefficients in the equation giving the scenario earthquake magnitude with the fault segment approach [4].

Fault Type	a coefficient	b coefficient
Straight Slip Fault	5,16	1,12
Normal Fault	4,86	1,32
Reverse Fault	5.00	1,22
All Fault Types	5,08	1,16

SDS; the short period is the acceleration coefficient (dimensionless) and can be evaluated by;

$$SDS = SS \times FS \tag{2}$$

where; SS: Short period spectral acceleration value; FS: Local Ground Effect Coefficient for the short period region.

SDS is calculated from the Earthquake Hazard Map of Turkey according to the earthquake ground motion level, local soil class, latitude, and longitude and is taken from the website of AFAD Presidency (www.tdth.afad.gov.tr).

Vertical soil stress (σ_{vo}) is the vertical soil stress of the depth taken from SPT with a unit of kN/m^2.

$$\sigma_{vo} = \gamma \times h \tag{3}$$

γ : The natural unit weight of the soil (If the soil is saturated with water, the saturated unit weight, γ_d, is used). Its unit is kN/m^3, h : SPT depth (m).

Effective Vertical Stress (σ'_{vo}): It is the effective vertical soil stress at SPT depth. Its unit is kN/m^2.

$$\sigma'_{vo} = \sigma_{vo} - (\gamma_{water} \text{ x } h_{water}) \tag{4}$$

σ_{vo}:Vertical soil streess (kN/m^2), γ_{water}:Unit volume weight of water (kN/m3), h_{water}:Groundwater level height (m).

C_N: It is the geological stress (depth) correction coefficient applied in cohesionless soils. If the calculated C_N value is greater than 1.70, the maximum value of 1.70 should be taken.

$$C_N = 9.78\sqrt{(1/\sigma'_{vo})} \leq 1.70 \tag{5}$$

C_R: SPT is the rod length correction coefficient, C_S: SPT is the sampler type correction coefficient, C_B: SPT is the drill diameter correction coefficient, C_E: SPT is the energy ratio correction coefficient. SPT correction coefficients are given depending on the depth and the relevant coefficients are used in the calculations (TSC-2018).

Adjusted SPT Hit Count ($N_{1.60)}$: Corrected SPT beat count without units. $N_{1,60}$ is always used in liquefaction analysis. The N_{60} has no C_N correction.

$$N_{60} = N \text{ x } C_R \text{ x } C_S \text{ x } C_B \text{ x } C_E$$

$$N_{1,60} = N_{60} \times C_N \tag{6}$$

Here; N : SPT impact number obtained from the field, C_N : Cover load correction coefficient, C_R : Rod length correction coefficient, C_S: Sample receiver correction coefficient, C_B : Borehole diameter correction coefficient, C_E : Energy efficiency correction coefficient, and $N_{1,60}$: Adjusted SPT stroke count.

$N_{1,60f}$: The number of SPT hits corrected for the fines content is expressed using the α and β coefficients for the fines content.

$$N_{1,60f} = \alpha + \beta \,.\, N_{1,60} \tag{7}$$

$\alpha = 0 ;\beta = 1$ (IDI ≤ %5)
$\alpha = \exp[1.76\text{-}(190/IDI^2)] ; \beta = 0.99 + IDI^{1,5}/1000$ (%5 < IDI < %35)
$\alpha = 5.0 ;\beta = 1.2$ (IDI≥%35)

CRRM7.5: It is the cyclic resistance ratio against an earthquake with a moment magnitude of 7.5.

$$\text{CRRM7.5} = \frac{1}{34-\text{N1,60f}} + \frac{\text{N1,60}}{135} + \frac{50}{[10\text{N1,60f}+45]^2} - \frac{1}{200} \tag{8}$$

CM: It is the design earthquake moment magnitude correction coefficient.

$$\text{CM} = \frac{10^{2.24}}{Mw^{2.56}} \tag{9}$$

τR: It is liquefaction resistance. Its unit is kPa.

$$\tau\text{R} = \text{CRRM7.5}\times\text{CM}\times \sigma'_{vo} \tag{10}$$

τdeprem: It is the average cyclic shear stress in the soil resulting from an earthquake. Its unit is kPa.

$$\tau_{deprem} = 0.65\times \sigma_{vo} \times(0{,}4\times\text{SDS}) \tag{11}$$

Safety Condition Against Liquefaction (τR / τdeprem):

$$\text{FSL}= \frac{\tau\text{R}}{\tau\text{deprem}} \geq 1{,}1 \tag{12}$$

If the FSL value is greater than 1.1, there is no risk of liquefaction, and if it is small, there is a risk of liquefaction in the soil.

2.2.2. *Liquefaction Calculation Steps According to Shear Wave Velocity*

Iterative or Shear Stress Ratio (KGO): It is expressed as the iterative stress ratio (KGO) of the soil material below the groundwater [5].

$$\text{KGO}= \frac{\tau\text{ort}}{\sigma\text{vs}'}=0.65\times\frac{\sigma\text{vs}\times\alpha max\times\text{rd}}{\sigma\text{vs}'\times\text{g}} \tag{13}$$

Here;

τ_{ort}: It is the average value of the iterative shear stress caused by the earthquake and the coefficient of 0.65 is considered to be 65% of the maximum stress,

α_{max}: The largest (peak) acceleration,

g: gravitational acceleration,

σ_{vs}: The dynamic vertical stress at the investigated depth calculated from the shear wave velocity and the seismic wave period,

σ_{vs}': It is the effective dynamic vertical stress calculated with the same parameters and at the same depth.

Dynamic vertical stress and effective dynamic vertical stress are calculated in kPa units with the following mathematical expressions [5].

$$\sigma_{vs} = 2.45T\sum_{i=1}^{n} \Upsilon i Vsi$$
$$\sigma_{vs}' = 2.45T\sum_{i=1}^{n} \Upsilon i Vsi - 9.81(z-z_w)(\Upsilon sa - \Upsilon i) \quad (14)$$

Here; Υ: unit volume weight (gr/cm3), Υ_h: unit volume weight saturated with water (gr/cm^3),

T: earthquake wave period (s), z: layer depth under investigation (m), and zw: groundwater depth (m).

Effective Stress Corrected Shear Wave Velocity Standard penetration test (SPT) can be corrected using the following equation with effective stress in Vs, similar to the equation known to correct the number of impacts with effective stress [6,7].

$$Vsc = Vs\left(\frac{Pa}{\sigma v'}\right)^{0.25} \quad (15)$$

Here; V_{sc} is the effective stress-corrected shear wave velocity and Pa is a reference stress known as atmospheric pressure.

Shear Resistance Ratio (KDO) For the corrected values of shear wave velocity (Vs) or SPT impact number obtained from field studies, the KDO value that separates liquefaction and non-liquefaction is called the shear resistance ratio. KDO is physically the natural resistance of the ground.

Andrus and Stokoe II (1997; 1999; 2000), and Uyanık (2002) proposes the following relationship between KDO and V_{sc} in their studies [8,9,10 and 11].

$$KDO = \left[a\left(\frac{VSc}{100}\right)^2 + b\left(\frac{1}{VSmax - Vsc} - \frac{1}{VSmax}\right)\right] \times MSF \quad (16)$$

Here; V_{sc}: Corrected shear wave velocity, V_{smax}: Upper limit value of corrected shear wave velocity where liquefaction can occur, a and b: Curve-appropriate parameters and MSF: Magnitude scale factor.

$$MSF = \left(\frac{Mw}{7.5}\right)^n \quad (17)$$

Here; M_w is the moment magnitude and n is an exponential constant.

It varies between V_{smax}=220-250m/s depending on the fineness content of the ground. The relationship between V_{smax} and the fineness content (FC) of the soil is expressed below.

V_{smax}=250m/s FC⩽ %5 Sand
V_{smax}=250 – (FC-5)m/s %5<FC<%35 Sand
V_{smax}=220m/s FC⩾%35 Sandand Silt

Factor of Safety (FS); The most common way of determining liquefaction hazard is the factor of safety.

$$FS=KDO/KGO \tag{18}$$

As a general rule, it indicates that liquefaction will occur when FS⩽ 1.

2.2 Development of Soil Liquefaction Analysis with Visual Basic

The determination of the risk of liquefaction in soils takes place within a certain chain of rules, regardless of the regulation. Applying these rules again in each soil analysis takes time and invites mistakes to be made. For this reason, software has been developed in which all the rules are written and the data will be entered and the program will direct the program to the result, and thus calculations and analyzes are made possible both visually and without going beyond the rules, by entering the data.

The software developed in this study was developed with the VBA (Virtual Basic for Application) programming language working on Excel, which is frequently used by researchers in the field of engineering. There are 4 types of analysis possible in the developed software; 1. Liquefaction Risk Analysis According to TSC-2018 [12], 2. Liquefaction Risk Analysis According to TSC-2007, 3. Liquefaction Analysis According to Shear Wave Velocity, 4. Comparative Liquefaction Analysis Geotechnical Report.

The software is run by using the tables of the Excel application with the VBA programming language. For each new ground analysis, a new page is opened in the Excel application and named "Analysis_(AnalysisName)". All data related to the study are organized in tables on this page. For each soil analysis, it is possible to compare according to TSC-2018, according to TSC-2007, Shear Wave Velocity (an analysis method in accordance with TSC-2007 regulation), and a comparative module between them (Figure 1).

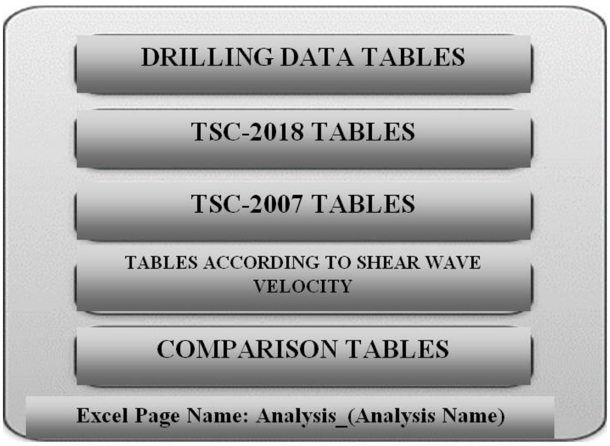

Figure 1. Arrangement of Analysis with Tables in the Developed Software.

Importing data belonging to other analyses recorded from the same Excel file, importing data belonging to other analyses recorded from another Excel file (produced with this program), and recording as a PDF file in a certain order according to the relevant analysis types are the features developed for this program. The operation of this program is done by creating tables, printing formulas, making controls, creating graphics, small code groups named module and interface forms named userform.

In addition, there is an Excel sheet called “data” to be used in all analyses and a list of analyses is kept. This page contains tables with a list of analyses, and options for soil types, DTS types, sampler types, borehole diameters, ram types.On the login screen of the software, what type of analysis should be done first is asked. This step is the first step of the software and starts with calling the userform named U1_GIRIS. For this, a shortcut (Ctrl+O) is defined so that the program can be started when Excel is first opened. As a first step, the login page is opened by using this shortcut (Figure 2). These 3 methods were preferred in order to compare the analyzes with the highest accuracy and the clearest results.

Figure 2. Start Page of Developed Software.

The flow chart of soil liquefaction analysis programmed with VBA language is given in Figure 3. In this context, liquefaction risk analysis according to TSC-2018 is selected on the login screen, respectively, and then "open analysis" should be selected in the analysis interface according to shear wave velocity or other methodologies.

Afterward, drilling data and soil parameters are entered into the relevant interface, in the meantime, SPT-N correction is made. In the next step, the liquefaction resistance is calculated and then the liquefaction risk safety factor is found and compared. Finally, the necessary information for the report is entered into the relevant interface and the analysis report is saved and retrieved.

3. RESULTS

The program prepared within the scope of the study takes the user step by step from the beginning to the end of the analysis. It is not possible to proceed to the next step without entering the desired data. It is not possible to manually change the parameters (fixed coefficients, etc.) that should not be changed, so as a result of the analysis, the user cannot play with the results as he wishes. The reliability of the geotechnical evaluation is assured.

With the Import Data button, the user can directly transfer other analyzes in the program to the analysis to be created or export from another Excel. Likewise, with this button, it can mark the desired data and call only that data (SPT 15-30, Unit Volume Weight, etc.).

The program automatically provides access to the soil type according to the SPT-N60 value (Figure 4). The program automatically provides the α and ß values according to the fine grain content in the 2018 Earthquake Code (Figure 5). Based on the corrected SP-N value, the depth dependent ground plot is given in Figure 6.

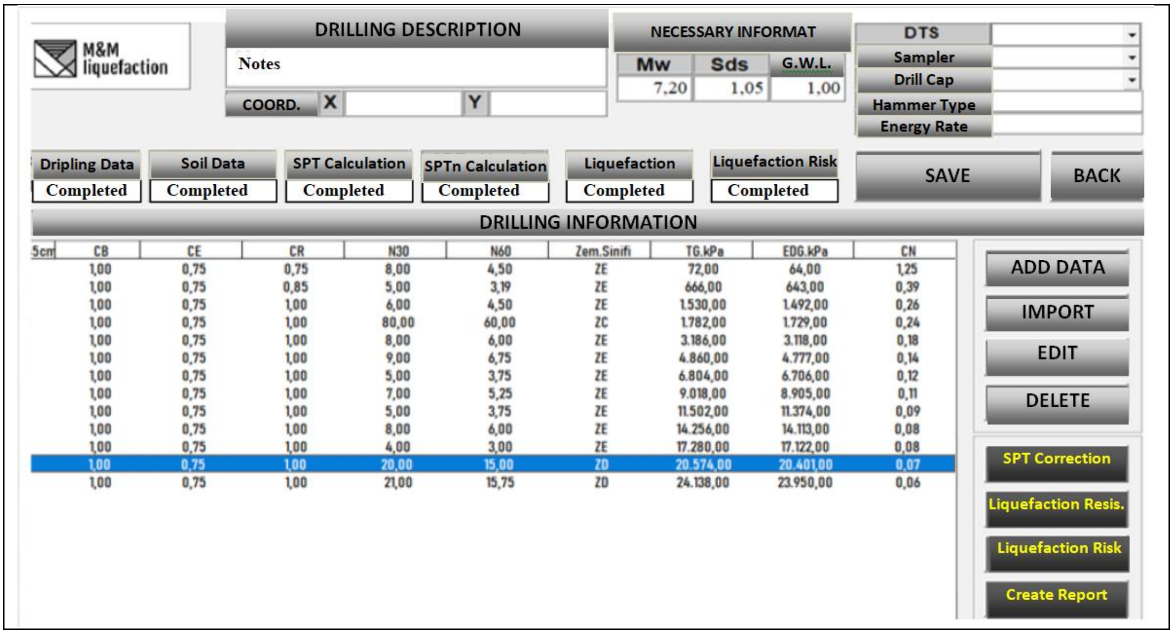

Figure 4. Soil Classification and SPT-N60 Calculation Module.

The program provides the user with results according to 3 different Liquefaction Analysis. For each analysis, the relationship between SPT-N and depth dependent graph can be observed separately and thus more precise engineering judgments can be made. Analyzes can be made by entering the data according to 2007 and 2018 and Shear Wave Velocity and the results can be obtained with the Comparative Liquefaction Analysis of Geotechnical Report button.

SPT N CORRECTION									
Sample	Depth m	Soil Type	N1.60	TG.kPa	EDG.kPa	IDI	alfa	beta	N1.60F
1,00	1,80	Filling	7,65	30,60	22,60	90,00	5,00	1,20	14,18
2,00	3,30	Clay	3,89	90,00	67,00	90,00	5,00	1,20	9,67
3,00	4,80	Clay	3,83	176,40	138,40	99,00	5,00	1,20	9,59
4,00	6,30	Clay	3,41	289,80	236,80	99,00	5,00	1,20	9,09
5,00	7,80	Clay	3,15	430,20	362,20	56,00	5,00	1,20	8,78
6,00	9,30	Clay	2,98	597,60	514,60	57,00	5,00	1,20	8,57
7,00	10,80	Clay	1,42	792,00	694,00	57,00	5,00	1,20	6,71
8,00	12,30	Sand	1,75	1013,40	900,40	42,00	5,00	1,20	7,10
9,00	13,80	Sand	1,11	1261,80	1133,80	42,00	5,00	1,20	6,34
10,00	15,30	Sand	1,61	1537,20	1394,20	42,00	5,00	1,20	6,93
11,00	16,80	Sand	0,73	1839,60	1681,60	42,00	5,00	1,20	5,88
12,00	18,30	Sand	3,36	2169,00	1996,00	8,00	0,30	1,01	3,70
13,00	19,80	Sand	3,26	2525,40	2337,40	8,00	0,30	1,01	3,60
14,00	21,30	Clay	1,15	2908,80	2705,80	8,00	0,30	1,01	1,47
15,00	22,80	Clay	0,81	3319,20	3101,20	8,00	0,30	1,01	1,12
16,00	24,30	Clay	0,76	3756,60	3523,60	8,00	0,30	1,01	1,07

Figure 5. Module for Determination of α and ß values according to SPT-N Correction and Fine Grain Content.

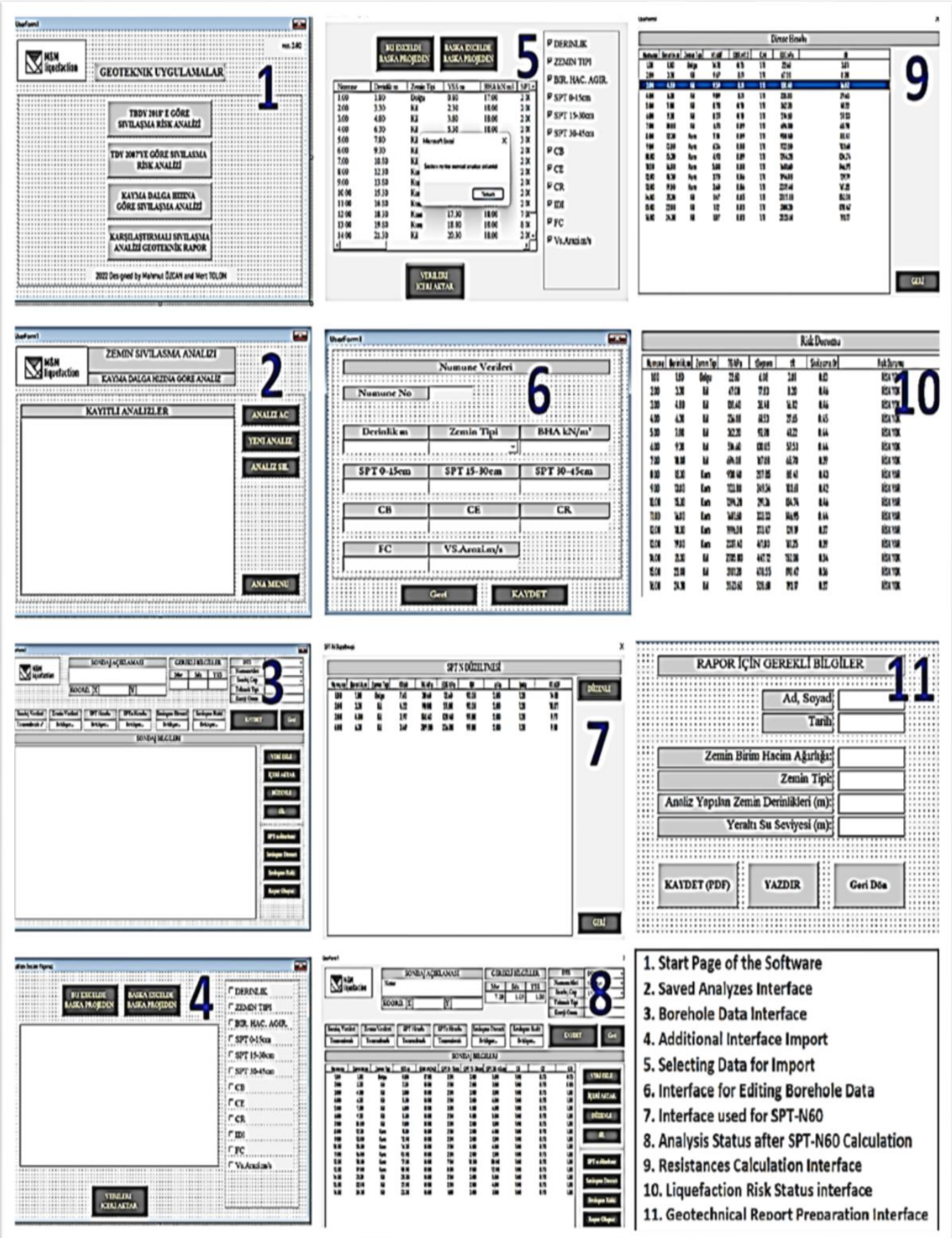

Figure 3. Flow chart of developed soil liquefaction analysis software based on VBA.

An example evaluation of the relationship of Depth - Corrected SPT-N Value Graph Obtained with the Developed Module is given in Figure 6.

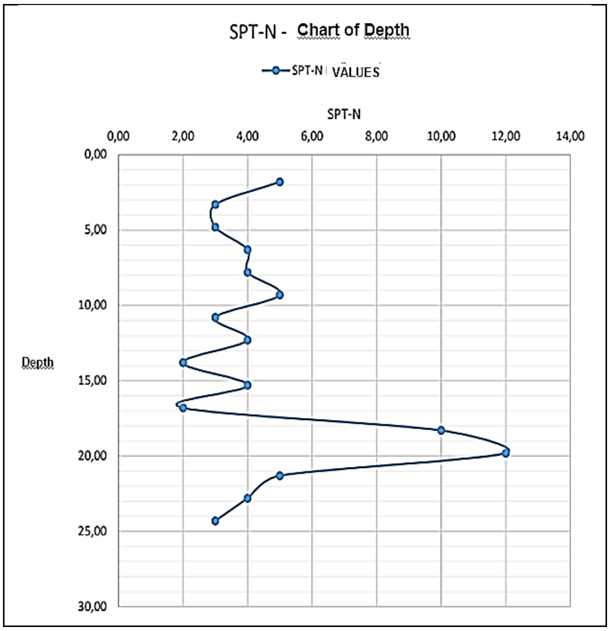

Figure 6. Depth - Corrected SPT-N Value Graph Obtained with the Developed Module.

A report can be obtained for each analysis and the information on the report can be entered and either automatically printed or saved in PDF format if desired. Thus, institutional memory will be provided with the relevant program and the existing geotechnical report database (Figure 7).

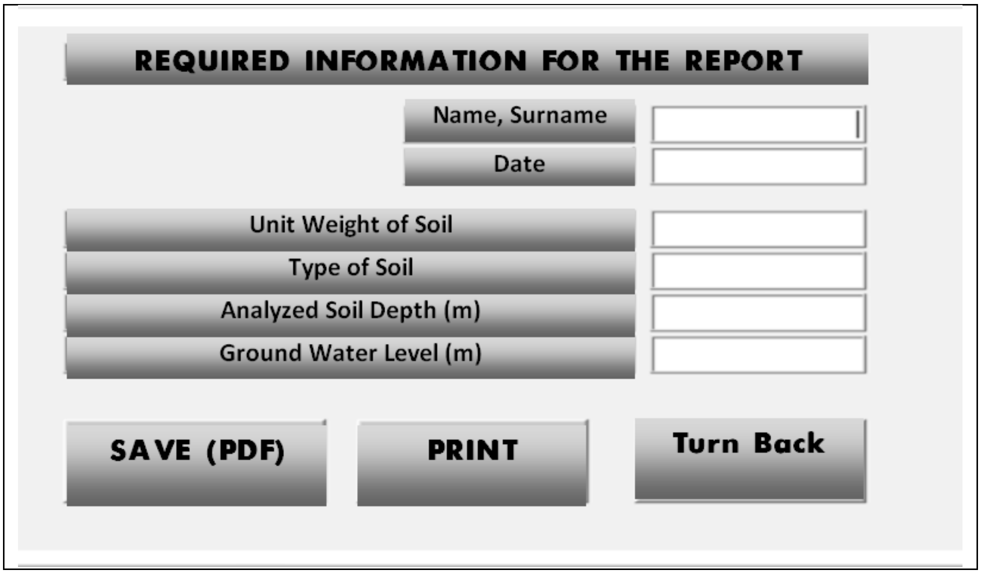

Figure 7. Geotechnical Report Saving and Printing Module.

The reliability of the results was compared with the program developed by comparing with traditional methods. In this sense, the graph of the variation of the liquefaction risk in the ground according to the TSC-2007, Shear

Wave Velocity methodology and TSC-2018, obtained with the program developed based on a sample case study, is presented in Figure 8. It has been seen that the results of the liquefaction risk safety factor required to be obtained according to the relevant regulations, both with simplified hand calculations and the values obtained from the program, are extremely significant and convergent.

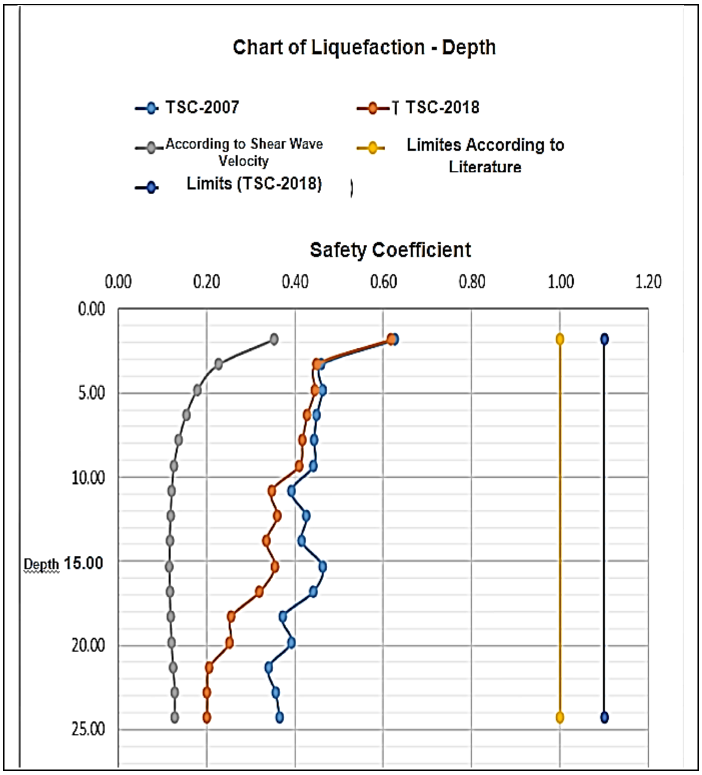

Figure 8. Liquefaction Risk – Depth Change Graph obtained with the Developed Program.

4. DISCUSSION AND RECOMMENDATIONS

With the program created within the scope of the study, it is possible to make an early intervention since the determination of soils at risk of liquefaction is made by examining certain parameters. Soil grouting, dynamic compaction etc. on soils that are found to be risky during soil surveys and studies. The intergranular spaces should be filled by using remediation methods, the injected material should be resistant to water and divert water from the environment, and should be of a type that will increase the resistance by tightening the ground, and in this way, the risk of liquefaction in the ground can be reduced.

By using this program, the decision-making mechanisms of field or office engineers in terms of liquefaction can be accelerated. An economical solution can be found by obtaining soil liquefaction analyses as a preliminary research at the beginning of the project, in accordance with the regulation, in a fast and reliable manner, and by making the risky-predicted soils safer with soil improvement methods. The development of the program by correcting itself will contribute to future studies. No comparison has been made with any other analysis method, and this is seen as a limitation of the study and is planned to be included in future studies.

When the developed program and the results obtained are examined, it is thought that a program that presents the results to the user more clearly in terms of the engineer's interpretation, since the program progresses in a more understandable and sequential manner compared to the previously developed liquefaction analysis programs based on MS Excel in the literature.

Given the increasing demand for safe and economically viable construction practices in earthquake-prone regions such as Turkey, the integration of the Visual Basic-based liquefaction analysis tool into the broader framework of the 2018 Turkish Seismic Code holds significant potential. The tool, designed to rapidly and accurately assess soil liquefaction risk using on-site data and laboratory tests, aligns well with the objectives of the 2018 Turkish Seismic Code by addressing the critical soil factors contributing to structural failures. Its application can be expanded to other geotechnical standards within the 2018 Turkish Seismic Code by incorporating additional parameters and methodologies relevant to diverse soil conditions and seismic responses. This approach not only facilitates early and effective interventions but also ensures that construction projects commence with realistic budgets and robust structural models. By continuously updating the tool with the latest regulatory requirements and incorporating comparative analyses with other existing methods, it can serve as a comprehensive and adaptive solution for geotechnical engineers, thereby enhancing the overall resilience and safety of new and existing buildings in seismic zones.

As a future work-study, the addition of other liquefaction analysis methods in the literature in the past and today and other methods that will be included in the following regulations will be added to the analysis model, and the development of the database with the existing different land data is considered as future studies.Also, as a future work plan to effectively expand this study within construction projects, several steps can be taken. First, integrating the Visual Basic-based liquefaction analysis program into a broader suite of geotechnical tools used by engineering firms can enhance its adoption and utility. By ensuring compatibility with other industry-standard software, the program can become a valuable component of a comprehensive geotechnical analysis toolkit. Additionally, conducting field trials across diverse geographical areas and soil types can validate the program’s accuracy and reliability in various conditions, encouraging wider use. Collaborating with regulatory bodies to update and refine the program based on the latest seismic codes and best practices will also ensure its relevance and compliance with evolving standards.

5. CONCLUSION

The findings demonstrate that the application can significantly improve the safety and reliability of construction projects by enabling early and precise intervention. By incorporating methods such as soil grouting and dynamic compaction, the risk of liquefaction can be mitigated, ensuring that new structures do not contribute to the existing stock of unsafe buildings. Furthermore, the study underscores the importance of considering soil-structure interaction in seismic design, as neglecting this aspect can lead to severe infrastructure damage.The program's ability to present results clearly and sequentially makes it a valuable tool for engineers, offering a more user-friendly experience compared to existing MS Excel-based liquefaction analysis programs. However, the study acknowledges its limitation in not comparing the developed method with other analysis techniques, which is an area for future research.

In conclusion, the integration of this innovative liquefaction analysis tool into geotechnical practice represents a significant advancement in earthquake risk mitigation. Future work should focus on expanding the program's database, incorporating additional liquefaction analysis methods, and continuously updating the model in line with evolving seismic regulations. By doing so, the program can further enhance its accuracy and applicability, contributing to safer and more resilient construction practices in seismic regions.

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Declaration of Competing Interest

Competing interest statement declared by authors. This statement must also appear in your manuscript before the references.

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