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Digital Transformation Solution for Identification of Geotechnical Parameters Using Statistical Data Analysis

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ABSTRACT

Currently, there is a large boom in the construction of new developments, infrastructure, and transportation projects in the Middle East. Geotechnical engineers are responsible to characterize the subsurface ground conditions, obtain design parameters and identify problematic subsurface ground conditions. Geospatial Information Systems combined with statistical algorithms can provide an efficient way for identifying soil parameters/hazards. GIS associates data with their location (coordinates). The spatial data analysis platform ArcGIS is used to determine soil parameters at unsampled locations. An automated workflow is developed to apply different interpolation algorithms providing engineers with an easy-to-use tool to determine the most accurate algorithm for use in a specific project. This technique is applied to assess the liquefaction potential in a project site in Dubai, United Arab Emirates. Four spatial data analysis algorithms: Inverse Distance Weighted (IDW), Natural Neighbour, Regularized Spline, and Tension Spline are applied to the measured data. The errors associated with the use of the different algorithms are computed and compared. The suitability of tzhe use of different algorithms is discussed.

Keywords: Digital Transformation, Data Analysis, Liquefaction, GIS

1. Introduction

The presence of existing subsurface ground information including stratigraphy, groundwater table, in situ, and laboratory test results is an integral part of the design and construction of any civil engineering project as required by codes of practice. This knowledge allows for defining potential hazards and problematic soils and preparing suitable foundation recommendations, accordingly. This leads to savings in the project cost, proper time scheduling, and reduction in unplanned problems and delays on site. Geospatial Information System (GIS) links data with location (coordinates) making it a useful tool to enable storage, analysis, and referencing of information related to the specified coordinates. This allows for two- and three-dimensional data modeling of subsurface ground stratigraphy. Alternatively, GIS may be used to show the variation of a specific parameter with time (e.g. seasonal variation in groundwater elevations) known as four-dimensional modeling.

Geospatial Information System (GIS) is used to achieve three goals. First is data management for archiving geotechnical data using geodatabases (a special type of database that includes geographic locations). The second is visualization and mapping to produce dynamic interactive maps for ease of access to sample data. Finally, “spatial data analysis” utilizes different methods to interpolate between samples to provide soil parameters in non-sampled areas. Several publications discuss the use of GIS techniques for geotechnical applications with some examples presented herein. O’Rourke and Pease, (1997) utilized GIS to map the liquefiable layer thickness for seismic hazard assessment to evaluate its effect on damage to structures/infrastructures. Parsons and Frost, (2002) implemented GIS techniques and statistical analyses to test the quality of the subsurface investigations employing SPT measurements as an input to the Krigin spatial data analysis algorithm. Abd Elsalam, (2012) applied geostatistical techniques to map problematic soils existing in the Sixth of October City, Giza, Egypt. Labib and Nashed, (2013) outlined the extent of expansive soils in the Toshka region to identify layers having large swelling potential. Singh et al., (2018) reviewed several case studies illustrating the different applications of GIS in geotechnical practice demonstrating the effectiveness of GIS as a tool to gather, present and analyze geographically referenced data. The case studies demonstrated the important role GIS plays in planning preliminary geotechnical investigations, locating project barriers, spatial data analysis of subsurface ground properties at inaccessible locations in addition to visualization and processing of geotechnical data.

In summary, the applications of GIS in geotechnical engineering can be based on one or more of three GIS powers (Wan-Mohamad and Abdul-Ghani, 2011).

Data Integration and Management: GIS allows users to integrate information obtained from different sources including reports or photos which reduce the time needed to retrieve the data as it is transformed into a smart archiving system. It also enables data storage from both digital and non-digital sources in one accessible location with capabilities to create, update and delete data.

Data Visualization and Mapping: data is visualized and delivered using layers, symbols, and map text utilizing interactive dynamic maps. Moreover, GIS applications provide strong two- or three-dimensional visualization. Clear visual presentations assist the stakeholders to make educated decisions.

Spatial Analysis: processing spatial data allows better use of data to reach an optimum solution for a spatial problem based on the input data.

Thematic rasters are digital representations of attributes such as temperatures, elevations, soil type/properties. The input data includes many sources e.g. scanned photos, satellite images, numerical values, etc. The pixel values can be associated with more than one attribute. The thematic raster represents the data at discrete locations. Mathematical algorithms (interpolators) are used to compute raster data at unsampled locations. Calculating the unknown value in between known points depends on spatial correlation. The concept of spatial correlation assumes that things closer together are more alike than those located further apart according to Tobler's first law of geography (Walker, 2021). In general, there is no advantage for a certain interpolation technique over another. The suitability of using a specific technique depends on the frequency and variability of the measured attributes. Typically, GIS specialists/analysts are needed to perform such studies (O'Sullivan and Unwin, 2010).

Early knowledge of soil nature saves cost and/or avoids redesigning. Engineers can use spatial data analysis of subsoil conditions to aid them in taking appropriate precautions during construction projects (Thitimakorn and Raenak, 2016). Data analytics, when combined with statistical algorithms, can be extremely effective in identifying soil parameters in the early project stages. Four spatial data analysis methods are applied to the geotechnical dataset: Inverse Distance Weighted (IDW), Natural Neighbour, Regularized Spline, and Tension Spline. The accuracy of each method is measured by removing known points from the input dataset. The values of these points are calculated using different spatial data analysis techniques and compared with the original data. The accuracy of each technique in obtaining the data is evaluated accordingly. Traditionally, geotechnical engineers are better trained to handle studies related to the characterization of subsurface ground conditions and the analysis and design of foundations, earth retaining structures compared to data management applications. The introduction of an easy-to-use application would encourage more geotechnical engineers to integrate data management applications in routine projects. The focus of this research is to develop a workflow to process geotechnical data obtained from field and/or laboratory tests. This workflow is automated to create a single, easy-to-use tool that utilizes the capabilities of ArcGIS Pro. The created tool can be used locally or shared via the web as a service that can be accessed by the internet. Additionally, a web-based dashboard application is developed using ArcGIS Online and JavaScript Programming Language to facilitate the management of geotechnical data. This application enables project stakeholders to access their data from any location, at any time, and on any device. This tool is applied to investigate the liquefaction potential at a site in Dubai. A comparison between the different raster creation algorithms is performed to showcase their applicability to the case study.

2. Workflow automation

The spatial analysis software "ArcGIS Pro 2.8" provides several methods for spatial data studies (ESRI, 2010). For better efficiency, a single tool is developed using ArcGIS model builder to automate the data analysis process and to create surfaces using different algorithms which include Inverse Distance Weighted (IDW), Natural Neighbor, Spline-Regularized, and Spline-Tension. An access geodatabase is created to include the boreholes records table. Manually entered borehole records include the soil parameter and geographic coordinates. ArcGIS Pro creates point features in the exact location of each borehole for visualization on the map. The automated workflow is illustrated in Figure 1. Blue boxes, yellow boxes and green boxes indicate an input, a process, and an output, repectively. The developed tool accepts two inputs: the boreholes coordinates (X, Y and Z) and associated soil parameters. When the engineer supplies the required input, the soil parameters at unsampled locations can be computed using the four algorithms resulting in the generation of four different results, as shown in Figure 1. The algorithm produces a pixel-based thematic raster which is a format not commonly familiar to most engineers. The developed application converts each thematic raster output to descriptive contour lines which is a easier to be understood by engineers. Figure 2 shows the interface of the developed tool. The tool interface is divided into two tabs: the first is "Parameters" which is used to input the coordinates and the other tab is "Environment" which contains output options.

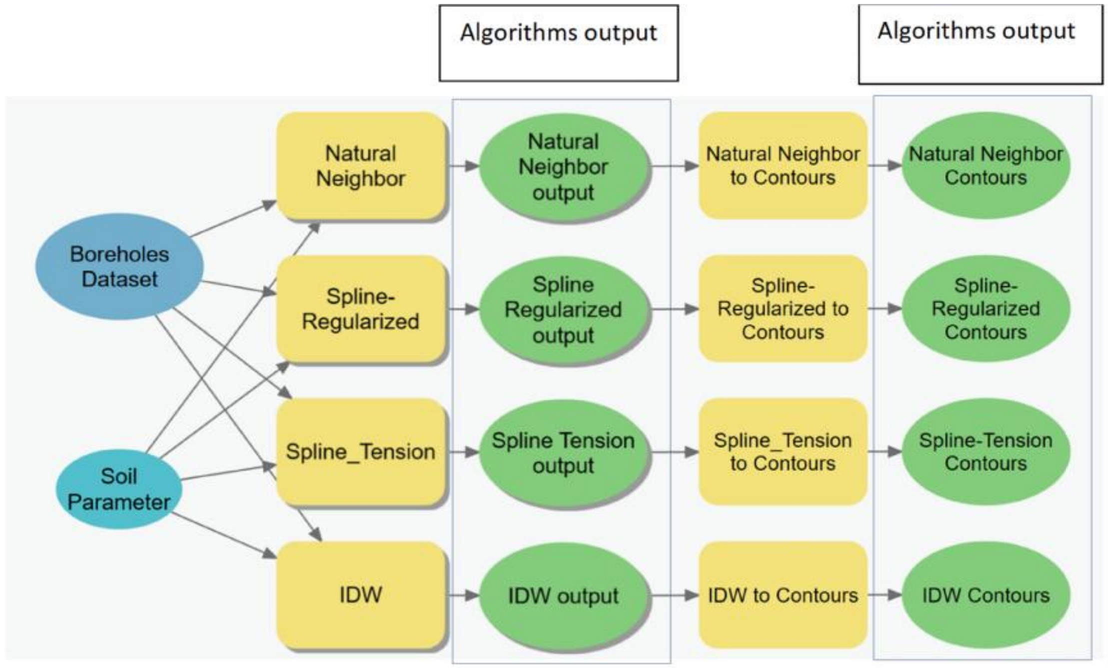


Figure 1: Automating the process of raster creation trials

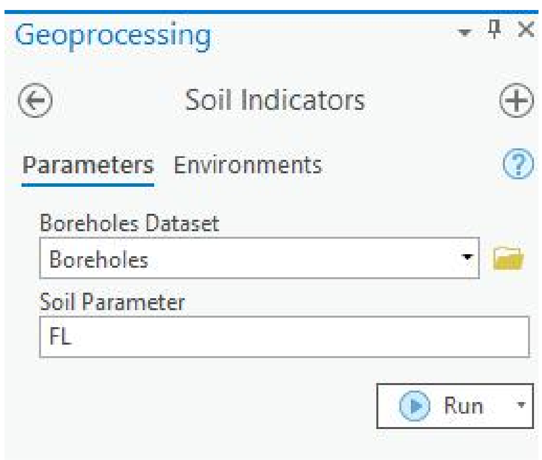


Figure 2: The created tool interface of the automated workflow

Addiiotnally, a web application is built using ArcGIS Online and JavaScript programming language which includes a map viewer to visualize the data. The application is responsive and can be viewed through a web browser, mobile browser, or tablet. Functionalities of the app include viewing layers by drawing order, bookmarks navigation, printing, sharing maps from other websites, identifying information about the geographic features in the map including soil reports as pdf or image. Also, there are tools for finding places on the map, selecting specific geographic features, zooming in/out/full extent, defining current location on the map, and scale bar. The developed application is applied to data from a site in Dubai, United Arab Emirates to map the liquefaction potential.

3. Case Study

3.1. Study Area

Over the past two decades, the United Arab Emirates and especially Dubai witnessed a boom in the construction of new buildings along its shoreline. A solution to increase beachfront properties was to create man-made islands/archipelago in the Persian Gulf, as shown in Figure 3. The reclaimed ground was constructed using sand dredged from the seafloor and transferred to the project location. The near-surface geology of coastal Dubai consists of an upper zone comprised of Quaternary marine, aeolian, sabkha, and fluvial formations underlain by Pleistocene calcarenite known as Gayathi formation which lies on top of Barzman formation which consists of fluvial sediments and poorly sorted conglomerates (Macklin et al., 2012; Elhakim, 2015).

Figure 3: Case Study Area

After completion of reclamation works, a subsurface investigation comprised of 26 boreholes down to a depth of 25 m was performed to cover the target area. The groundwater table was encountered at depths varying between 2.85 m to 4.00 m below the existing ground level. The ground stratigraphy is comprised of light brown to light grey fine to medium sand with shell fragments extending to depths of 13 m to 18 m below the natural ground surface. This layer is underlain by weak to very weak sandstone/calcarenite. The Standard Penetration Test was performed in all boreholes in the cohesionless layer with the measured SPT-N values presented in Figure 4. The recorded values varied between 7 and 50 indicative of loose to very dense sand. Sieve analyses were performed on representative sand specimens to determine the grain size distribution. The fines contents (smaller than 0.075 mm) are plotted versus depth in Figure 5.

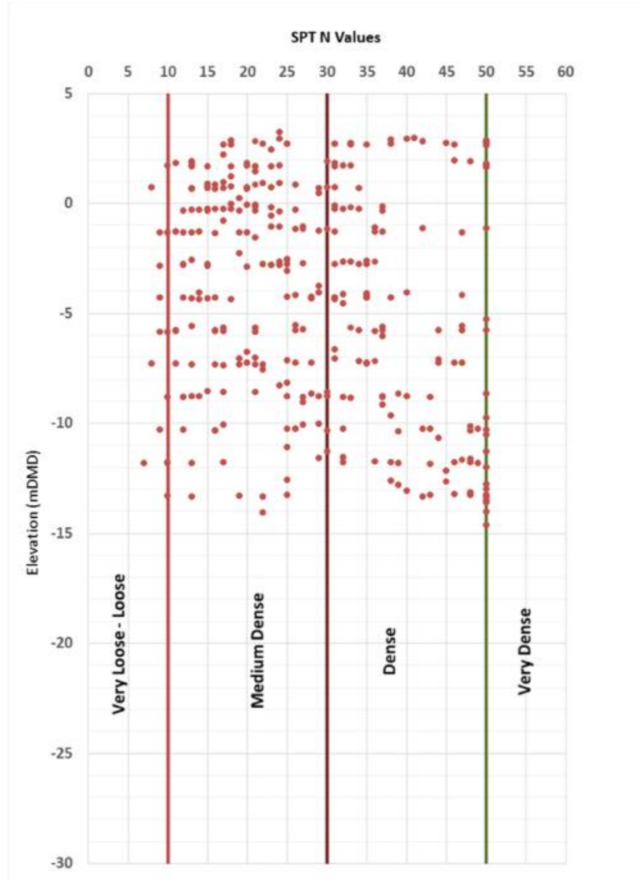


Figure 4: The measured SPT-N values versus elevation

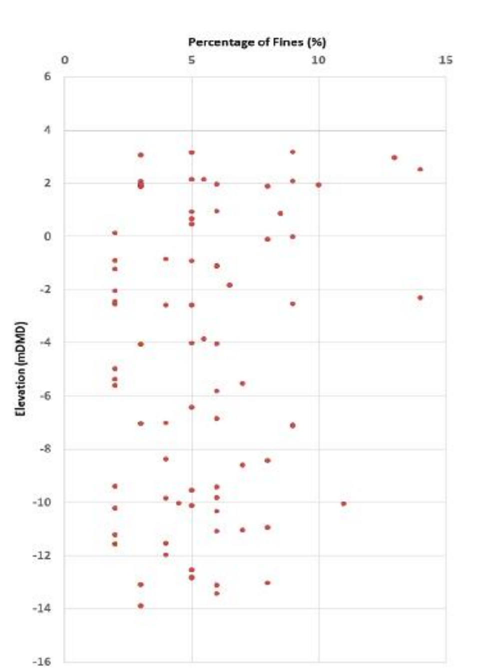


Figure 5: The fines contents versus elevation

3.2. Seismicity and Liquefaction

Although the United Arab Emirates is located in the stable block of the Arabian plate, it is situated close to a belt of strong seismic activity on the northern shore of the Arabian Gulf associated with the Zagros Thrust. Strong earthquakes in the south of Iran are felt in countries on the western shore of the Gulf including the United Arab Emirates (Al Khatibi et al., 2014). Liquefaction is one of the major hazards that endangers the safety of civil engineering structures. As seismic waves propagate towards the ground surface, the structure of sediments close to the surface breaks up, especially by cyclic shear waves. Water saturated loose sandy soils would densify increasing pore water pressure. If the excess pore water pressure increases to become equal to the effective overburden stress, the soil acts like a viscous liquid (Seed and Lee, 1967).

The seismic demanding of the soil required to cause liquefaction is known as cyclic stress ratio CSR defined as follows (Seed and Idriss, 1971; Youd and Idriss, 2001)

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right)r_d \quad ...(1)$$

Where □$_{av}$ is the average equivalent shear stress, □$_{vo}$' is the effective vertical stress, a_{max} is the maximum ground acceleration, g is the gravitational acceleration, □$_{vo}$ is the total vertical stress and r_d is a stress reduction factor to account for the flexibility of the soil column, which is represented by Equation 2, as a function of depth (z).

$$r_d = \frac{(1.000 - 0.4113z^{0.5} - 0.04052z + 0.001753z^{1.5})}{(1.000 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2)} \quad ...(2)$$

The soil resistance to liquefaction is expressed by the cyclic resistance ratio (CRR) which can be determined using laboratory tests on undisturbed soil specimens. However, in-situ stresses generally cannot be replicated in the laboratory. Furthermore, granular soil samples are highly disturbed to provide results representative of field performance. Thus, CRR is typically evaluated using in-situ tests (e.g. Standard Penetration Test, Cone Penetration Test, Piezocone Test). The CRR is evaluated using corrected soil penetration resistance $(N_1)_{60}$, duration of the earthquake (expressed by the earthquake magnitude scaling factor, MSF), effective overburden stresses, and soil fines content. The CRR is calculated according to the recommendations by Youd and Idriss (2001), using Equation 3.

$$C = \left[\frac{1}{3 - (N_1)_{6\ c}} + \frac{(N_1)_{6\ c}}{1} + \frac{5}{(1\ (N_1)_{6\ c} + 4\ )^2} - \frac{1}{2}\right] M \quad ...(3)$$

Where $(N_1)_{60cs}$ is the equivalent corrected SPT-N value for clean sand and MSF is the magnitude scaling factor. The safety of soil against liquefaction is determined by comparing the cyclic resistance ratio (CRR) of a soil layer to the earthquake-induced Cyclic Shear Stress Ratio (CSR). In others words, the factor of safety against liquefaction equals CRR/CSR. In Dubai, the design seismic earthquake parameters are Richter magnitude M = 6.0 and ground acceleration a = 0.225g (Dubai Municipality, 2013; Department of Planning and Development – TRAKHEES, 2017). Accordingly, the factors of safety against liquefaction are computed and presented in Figure 6 with values ranging between 0.835 and 8.377. If the factor of safety is less the one, the soil is susceptible to liquefy with the occurrence of the design earthquake. A minimum factor of safety against liquefaction is specified by codes of practice. According to Dubai Building Regulations and Design Guidelines – Structural (2017), a factor of safety against liquefaction of 1.2 to 1.5 is required. Similarly, AASHTO (2017) specifies a factor of safety against liquefaction of 1.2 to 1.3.

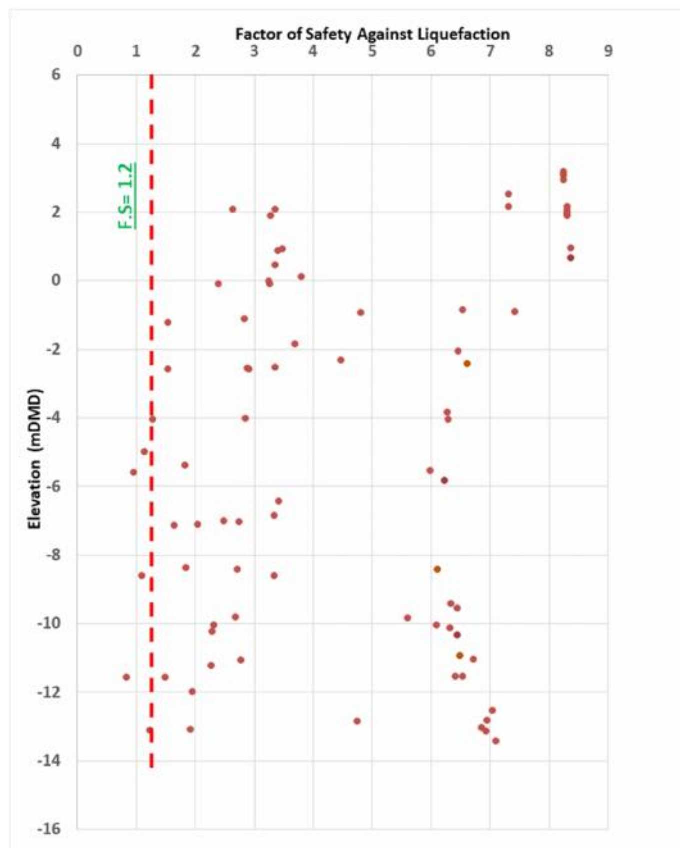


Figure 6: Factor of Safety against Liquefaction versus elevation

3.3. Spatial Data Analysis

The factors of safety against liquefaction are computed for the borehole data of the case study using a spreadsheet. The developed software reads the computed factors of safety at the different elevations for the boreholes. The results of three boreholes are eliminated from the dataset to compare the computed and predicted values at these locations. Four thematic raster algorithms are used to evaluate the values of the safety factors at unsampled locations. Comparisons between the computed and predicted values are made using the error (difference between the actual and predicted values) and error ratio (ratio of the error to the actual value). The results of these comparisons using the different thematic raster techniques are detailed below.

3.3.1 Inverse Distance Weighted (IDW)

The Inverse Distance Weighted method assumes that values near unsampled locations have a greater impact on the computed value estimate. Table 1 presents the actual safety factors against liquefaction compared with the ones computed using the IDW method at the three eliminated locations. The table shows the error and error ratios at each point. The error ratios vary between 0.144 and 0.65 with an average error ratio of 0.368 at an elevation of +1.8 DMD. At an elevation of -1.3 DMD, the error ratios vary between 0.06 and 1.763 with an average error ratio of 0.637. The average error ratio is 0.079 at an elevation of -8.1 DMD, with error ratios ranging between 0.009 and 0.164. Finally, the average error ratio at the three elevations is 0.361.

Table 1: Actual and IDW Computed Liquefaction Safety Factors

Elevation (m) DMD	Borehole	IDW	Real Value	Error	Error Ratio
+1.80	BH04	7.062	8.252	1.190	0.144
	BH23	5.611	3.401	2.210	0.650
	BH25	5.682	8.252	2.570	0.311
-1.30	BH05	4.255	1.540	2.715	1.763
	BH22	4.083	4.473	0.390	0.087
	BH25	3.469	3.690	0.221	0.060
-8.10	BH20	3.199	2.748	0.451	0.164
	BH23	1.667	1.652	0.015	0.009
	BH25	3.549	3.339	0.210	0.063
				Average Error Ratio	0.361

3.3.2. Natural Neighbour

The Natural Neighbour (NN) is another spatial data analysis technique that uses the Thiessen polygon (Voronoi) to find the Natural Neighbor for a cell based on the area weight rather than the distance. The Natural Neighbor method locates the subset of input samples that are closest to a query point and applies weights based on proportionate areas to them to calculate a value (Ikechukwu et al., 2017). Table 2 shows the actual computed liquefaction safety factors and values obtained using the Natural Neighbour. As shown, the error ratios vary between 0.201 and 0.650 with an average error ratio of 0.363 at an elevation of +1.8 DMD. At an elevation of -1.3 DMD, the error ratios vary between 0.002 and 1.568 with an average error ratio of 0.549. The average error ratio is 0.078 at an elevation of -8.1 DMD with error ratios ranging between 0.011 and 0.197. The average error ratio at the three elevations is 0.330, indicative of slightly better predictions compared to the IDW algorithm.

Table 2: Actual and Natural Neighbor Computed Liquefaction Safety Factors

Elevation (m) DMD	Borehole	Natural Neighbor	Real Value	Error	Error Ratio
1.80	BH04	6.592	8.252	1.660	0.201
	BH23	5.613	3.401	2.212	0.650
	BH25	6.282	8.252	1.970	0.239
-1.30	BH05	3.955	1.540	2.415	1.568
	BH22	4.481	4.473	0.008	0.002
	BH25	3.411	3.690	0.279	0.076
-8.10	BH20	3.288	2.748	0.540	0.197
	BH23	1.695	1.652	0.043	0.026
	BH25	3.375	3.339	0.036	0.011
				Average Error Ratio	0.330

3.3.3. Spline (Regularized & Tension)

The Spline technique resembles stretching a rubber sheet to touch all the sample values keeping smooth lines with reduced curvature. The Regularized Spline method creates a smooth gradually changing surface with values that may lie outside the sample data range (Rogerson, 2015). Both methods are applied to the dataset with the actual and computed liquefaction safety factors presented in Tables 3 and 4 for Spline-Regularized and Spline-Tension computed liquefaction safety factors, respectively. Using the Spline Regularized algorithm, the error ratios vary between 0.103 and 0.539 with an average error ratio of 0.301 at an elevation of +1.8 DMD. At an elevation of -1.3 DMD, the error ratios range from 0.107 to 0.516, with an average of 0.245. At an elevation of -8.2 DMD, the average error ratio is 0.2 with error ratios ranging from 0 to 0.474. At the three elevations, the average error ratio is 0.249 which is smaller than the IDW and Natural Neighbour methods. The use of the Spline-Tension algorithm leads to error ratios varying between 0.074 and 0.317 with an average value of 0.238 at an elevation of +1.8 DMD. At an elevation of -1.3 DMD, the error ratios vary between 0.111 and 0.535 with an average of 0.354. At an elevation of -8.1 DMD, the average error ratio is 0.338 with values ranging between 0.134 and 0.572. At all three elevations, the average error ratio is 0.310 using the Spline-Tension algorithm.

Table 3: Actual and Spline-Regularized Computed Liquefaction Safety Factors

Elevation (m) DMD	Borehole	Spline-Regularized	Real Value	Error	Error Ratio
+1.80	BH04	12.701	8.252	4.449	0.539
	BH23	3.750	3.401	0.349	0.103
	BH25	6.089	8.252	2.163	0.262
-1.30	BH05	2.335	1.540	0.795	0.516
	BH22	4.951	4.473	0.478	0.107
	BH25	3.278	3.690	0.412	0.112
-8.10	BH20	4.050	2.748	1.302	0.474
	BH23	1.652	1.652	0.000	0.000
	BH25	3.756	3.339	0.417	0.125
				Average Error Ratio	0.249

Table 4: Actual and Spline-Tension Computed Liquefaction Safety Factors

Elevation (m) DMD	Borehole	Spline-Tension	Real Value	Error	Error Ratio
1.80	BH04	5.570	8.252	2.682	0.325
	BH23	3.150	3.401	0.251	0.074
	BH25	5.640	8.252	2.612	0.317
-1.30	BH05	2.180	1.540	0.640	0.416
	BH22	2.080	4.473	2.393	0.535
	BH25	3.280	3.690	0.410	0.111
-8.10	BH20	1.900	2.748	0.848	0.309
	BH23	1.430	1.652	0.222	0.134
	BH25	1.430	3.339	1.909	0.572
				Average Error Ratio	0.310

3.3.4 Discussion and data visualization

Figure 7 presents the error ratios for the four applied techniques which range between 0.249 and 0.361. The smallest error ratio is realized when using the Spline-Regularized technique. Curtarelli et al., (2015) reported that the IDW algorithm does not produce the accurate results when applied to data high variability. Similarly, the Natural Neighbour algorithm is not suitable for use with data showing large (Musashi et al., 2018). Furthermore, the Natural Neighbor does not predict samples that are outside of the outer input samples (Ikechukwu et al., 2017). The Spline Regularized method creates a smooth gradually changing surface with values that may lie outside the sample data range which results in better predictions of soil parameters in unsampled locations. On the other hand, the Spline Tension method creates a less smooth surface with values more closely constrained by the sample data range (Oyana, 2020). In conclusion, the Spline Regularized algorithm provides better predictions for projects with large variations in values compared with other techniques

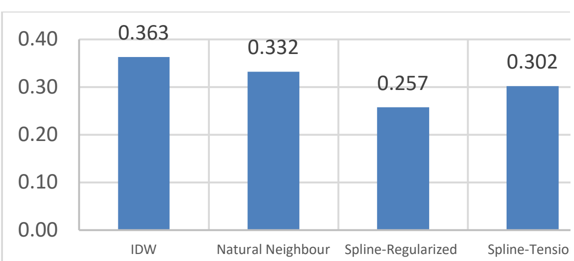
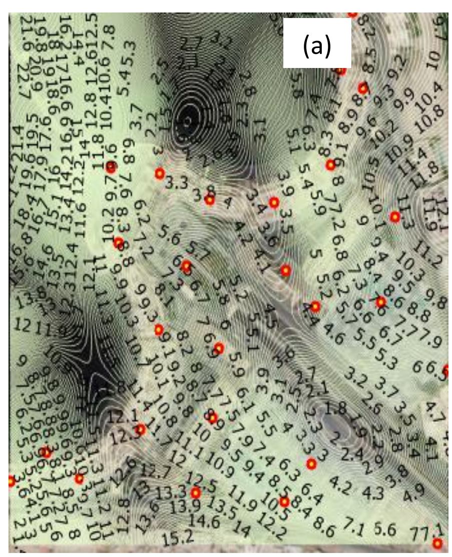


Figure 7: Average error ratios obtained using the different thematic raster techniques

Engineers are accustomed to working with contour lines; however, converting the thematic dataset to contour lines would be time consuming; thus, a conversion to contour is added to the workflow to facilitate engineering. It does not require additional work on the engineer's part; it is accomplished automatically via the aforementioned automated tool. "ArcGIS Pro 2.8" is used to visualize the factor of safety against liquefaction creating two-dimensional contour lines at different elevations. Figures 8-a, 8-b, and 8-c show the two-dimensional contour line maps for the liquefaction safety factor over the project area at elevations of +1.8 m DMD, -1.3 m DMD and -8.1 m DMD, respectively. The shown safety factors are calculated using the Spline-Regularized algorithm because it results in the least average error ratio. These contour maps facilitate the identification of zones that are prone to liquefy with the occurrence of the design earthquake. Based on the data visualization, the designer can perform further ground investigations in areas with low factors of safety to verify the presence of liquefiable layers. Alternatively, special foundation considerations/ground improvement techniques may be applied to ensure the safety of the structures.



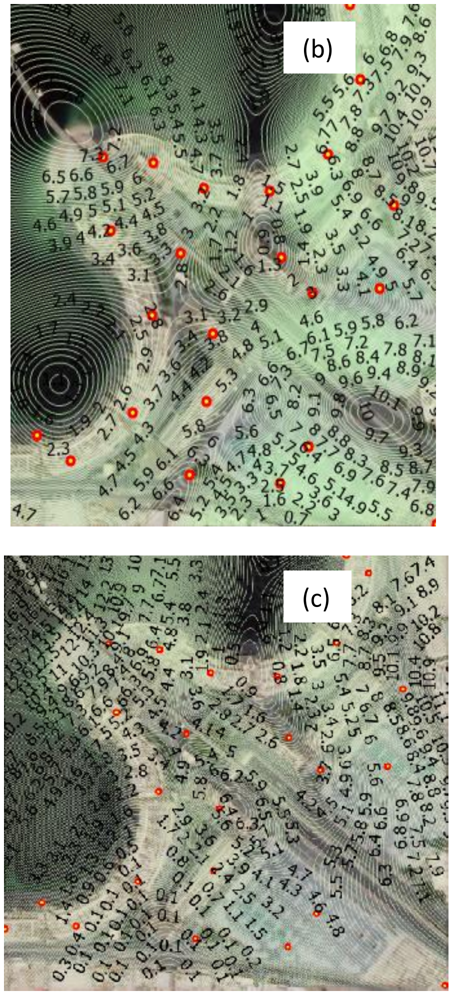


Figure 8: Contour Maps of liquefaction safety factors at the case study area at elevations (a) +1.8 m DMD, (b) -1.3 m DMD and (c) -8.1 m DMD

4. Geotechnical Data Management Dashboard

Geotechnical monitoring systems must be developed in response to the results of geotechnical design work. The dashboard is a graphical user interface that displays KPIs (key performance indicators) pertaining to the geotechnical project in question. It is also used to create progress reports and to serve as an informative data visualisation tool, among other functions. As shown in Figure 9, the dashboard was created using ArcGIS and the JavaScript programming language in order to be web-based. The web framework is built for managing geotechnical data including both the boreholes data and the Spatial data analysis results. The application helps engineers and decision-makers to have indicators about the site in the same region in future projects. This optimizes money, time, and effort.

On the right-hand side, it displays the total number of boreholes that have been collected as well as the average groundwater table. At the right bottom it shows the list of points that have factor of safety against liquefaction less than 1.2. At the middle bottom, the bar chart illustrates the liquid limit for each borehole. This dashboard can be customized to show whatever geotechnical parameters as needed. The locations of the 26 boreholes are depicted on a map in the center of the page. Drag, zoom, borehole search, and measure are all available on the map, as are all mapping operations. At the bottom of the dashboard is a chart illustrating the relationship between the borehole and its resistance to the factor of safety against liquefaction (FL). Finally, the attribute values for each borehole are displayed in a dynamic window.

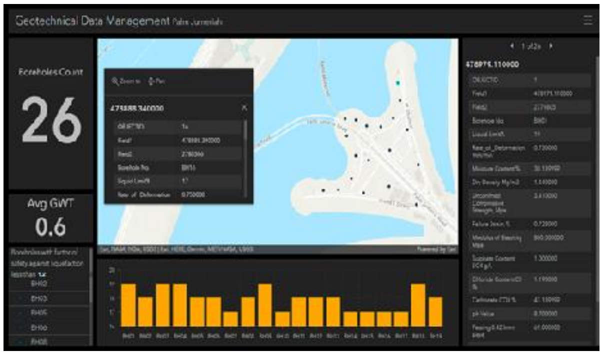


Figure 9: Contour Maps of liquefaction safety factors at the case study

In hazardous areas like the areas with high liquefaction susceptibility, defining the visualized measurements can help in early procedures for better disaster management. In the era of construction digitalization, it is effective to integrate data from multiple resources into one centralized hub. The geotechnical monitoring dashboard provides geotechnical data indicators which are accessible for anyone, anywhere, and from any device.

5. Conclusions

A Python-based automated workflow for the analysis of borehole data in order to generate indicators at unsampled locations has been developed to assist engineers without GIS experience in using the suggested workflow. Additionally, a web-based dashboard using the Javascript programming language was developed to visualise geotechnical data for more effective project data management. Additionally, it integrates with mobile devices to enable rapid geospatial field data collection and geotechnical data Management. A geodatabase of 26 boreholes is created for a site in Dubai. The database comprises the coordinates (Easting, Northing, and elevation) at different depths. The location data is linked to the soil properties at each elevation which include grain size distribution (D10, D30, D60), percentage fines (passing sieve #200), SPT-N values, etc. The factor of safety against liquefaction is computed for the granular soil layers based on the SPT resistance, grain size distribution, expected earthquake magnitude according to Dubai Municipalities requirements. The GIS program "ArcGIS Pro 2.8" is used to interpolate the liquefaction safety factor between the existing boreholes at different elevations. The results of three boreholes are eliminated from the database and used to compare the accuracy of the Computed results. Four spatial data analysis methods: Inverse Distance Weighted (IDW), Natural Neighbor, and Spline (Regularized and Tension) are applied and their results are compared with the actual safety factors.

The calculated liquefaction safety factors are highly variable, ranging from 0.835 to 8.377. As a result, Spline–Regularized and Spline–Tension are better suited to these conditions. On the other hand, the IDW and Natural Neighbor methods would not produce the best results because they are used in situations with a high density of sampling. This is demonstrated by the errors at an elevation of +1.8, -1.3, and -8.1 meters (reference to Dubai Municipality Datum) in the calculated values, which are 0.361, 0.330, 0.249, and 0.31 for IDW, Natural Neighbor, Spline–Regularized, and Spline–Tension, respectively. This method is easier to use than traditional methods for evaluating subsurface conditions. The zone maps developed for this research are based on current data, experience, and practice, and are used to define potential liquefaction locations. A thematic raster dataset and contour maps are generated, indicating un-sampled locations and assisting the engineer in taking appropriate precautions. Additionally, the raster is used to identify areas at risk of soil liquefaction.

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