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Modification of Subsurface Profile Layers using GIS

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Abstract
In the present study, the MASW test data and SPT-N values are used in Kriging technique to develop the layers for representing the subsurface in two-dimensional (2D) form. The word "kriging" is synonymous with "optimal prediction". In the MASW test, concepts of refraction analysis, time term method and tomographic inversion are used to calculate the shear wave velocity with respect to depth for a few selected locations in the IITM campus [1, 7, 8]. The shear wave velocities are generated for 1D and 2D subsurface profiles and soil classification is made using the results of average shear wave velocity of the top 30 m of the overburden (Vs30). The results of shear wave velocities indicate the presence of a low velocity layer near the surface underlain by approximately 10 m of sediments in the campus. The average shear wave velocity of the sediments is found to range between 270 and 414 m/s. Based on Vs30 values, it is noted that most of the campus area belongs to site “class D” with a few locations coming under “class C” as per the NEHRP site classification. The shear wave velocities predicted at different locations in the campus using the “Vs and SPT-N correlation” appear to be consistent with the SPT N-values. The MASW test data and SPT-N values from borelogs are used in the GIS to develop the subsurface profile for entire IITM campus using Kriging technique.

Keywords SPT-N values, kriging, shear wave velocitie

1. Introduction

Geographic Information System (GIS) can integrate and relate any data with a spatial ingredient of the data source. In GIS, it is easy to store, retrieve, manage and analyze geotechnical and geophysical data. Given that there is a large quantity of data in hard copy which is difficult to handle, this data can be handled more effectively by GIS [2, 4]. The common practice was and to some extent still is, to report geotechnical data as borehole logs and geophysical test data as a supplement of geotechnical surveys that is followed by the planning and designing of any civil engineering project. Geotechnical site characterization of large civil engineering projects typically requires three-dimensional (3D) data such as stratification of soil types, elevation of water table, soil properties at various depths. This produces large volumes of data that is difficult to manage and analyze. Systems have been developed for planning site investigations, interpreting site investigation data to generate a model of the ground conditions, classification of soil and rock, and the interpretation of geotechnical parameters [6, 9]. The conclusion is that the systems developed show the potential for applying knowledge-based system technology in geotechnical engineering.

It is a method of interpolation which predicts unknown values from the data observed at known locations. This method uses variogram to express the spatial variation, and it minimizes the error of predicted values which are estimated by spatial distribution of the predicted values. The use of kriging, a geostatistical technique, on SPT-N values allows creating a subsurface model of soil layers [1, 8]. The kriging has the ability to honour a true value at a sampled site and provides estimates from the data points in close proximity and its uncertainties at unmeasured sites. This procedure estimates the unsampled values by calculating the weights assigned to the individual neighboring points. These weights depend on the spatial relationship between the values and distances between the sampled and unsampled data points. These spatial relationships are quantified by constructing a semi-variogram.

2. Literature review

Goldfinger et al. (1997) [10] had used GIS to investigate the Cascadia Subduction Zone off the coast of Oregon, USA. By integrating geologic, geophysical, and morphologic data, they were able to determine slip rates of offshore faults, and estimate the areal extent of the active subduction zone. They also used the GIS as a visual aid to interpret the geologic structure.

Camp and Outlaw Jr. (1993) [2] devised a procedure for constructing subsurface profiles based on well log data and GIS. The system used a good database to create user defined cross-sectional profiles which can be interactively viewed using ArcInfo, with the goal of monitoring the groundwater resources and contaminant flow.

Chang and Park (2004) [3] developed a Web-based GIS application for efficient management of borehole and geological data. The borehole data is stored in a database. The system allows the clients to gather the statistics of the borehole data by searching the database. Nevertheless, for a user, it is difficult to add the datasets or store the sample data with different formats to the database.

Akiska et al. (2013) [11] determined the potential Pb-Zn ore zones in the subsurface environment of the Handeresi

Cu-Pb-Zn deposit by means of the surface and borehole geologic data for mining operations. For implementing this study, the Kriging interpolation method is preferred for surface modelling.

3. Georeferencing

Georeferencing is the process of scaling, rotating, translating and deskewing the image to match a particular size and position. Raster image is made up of pixels and has no particular size. The vectorised CAD/GIS drawing size is determined by the raster's pixel dimensions (the width and height of the raster in pixels). This is in turn determined by the image resolution. This image sizing will usually bear no relationship with the dimensions of the drawing that the raster represents.

Georeferencing is crucial to making aerial and satellite imagery, usually raster images, useful for mapping as it explains how other data such as the Global Positioning System (GPS) points relate to the imagery. Very essential information may be contained in data or images that were produced at a different point of time. It may be desired either to combine or compare this data with the collected data which is currently available. The latter can be used to analyze the changes in the features under study over a period of time.

3.1. GPS Data Collection

The relevant data were collected using GPS device available with the IIT Madras and are given in Table 1.

3.2 Procedure of Georeferencing

1. The data is imported to ArcGIS. Define the projection using the define projection tool and added X- and Y-coordinates for the collected data set.
2. The projection of the data set was selected as “UTM zone44 N” in the projected data set. Chennai lies in "UTM zone 44" and north of Equator.
3. From the tool bar menu, Georeferencing option should be selected.
4. After selecting Georeferencing tool bar, the given map is added.
5. Click zoom to layer so that the data point and map are visible.
6. Zoom to the upper left edge of the map and search for a crossing of a longitude and latitude. Now create a point on this cross using the function Add Control Points.
7. After marking the point, press right-click on the mouse and choose the option Input X and Y. A window will appear.
8. One can type the data in the window or drag points from the map to the data set.
9. Continue this for atleast four points.
10. Click on the link table to get X- and Y- coordinates of the source i.e., GPS data and map (Google map) [Table 2].

3.3 Results

The georeferenced map of the IIT Madras campus is shown in Figure 1. The residual errors associated with the georeferencing are given in fig

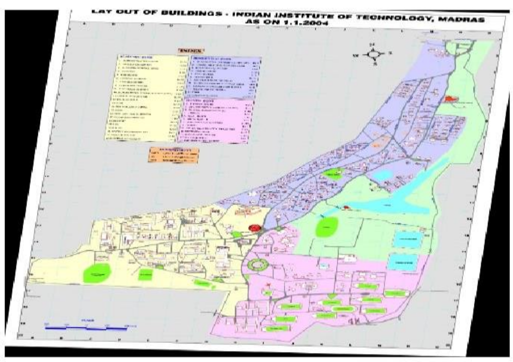

Figure 1. Georeferenced map of IIT Madras campus

Soil Layers at Different Depths From Borehole Data

Geotechnical data was basically collected from the geotechnical investigations carried out for the several major projects in the IITM campus. The GIS model developed currently consists of 23 borehole locations marked on the georeferenced IITM campus map of scale 1:20000 and the same is depicted in Figure 5.2. By using the excel sheet, the data is interpreted with top elevation, soil depth and rock depth at all borehole locations. This borehole data is imported into GIS tool called ArcMap and a shape file is created. The shape file is exported along with borehole information (Table 3) and then added to map. This is followed by kriging to develop the soil-rock interface and layer information at different depths.

Table 3 Complete borehole information given as input to GIS

BH ID	BH	Latitude (N)	Longitude (E)	SD (m)	RD (m)	TD (m)	TE (m)	SE (m)	RLE (m)
B1	KH-BH1	12.98452	80.23255	2.2	2.8	5	11.5	9.3	6.5
B2	KH-BH2	12.98422	80.23267	4	1.2	5.2	11.9	7.9	6.7
B3	BI-BH5	12.98985	80.22748	3.2	6.8	10	16.7	13.5	6.7
B4	BI-BH6	12.98988	80.22759	5	2.8	7.8	17.1	12.1	9.3
B5	NCCRDBH4	12.99211	80.22761	4	1	5	16.5	12.5	11.5
B6	NCCRDBH3	12.9923	80.22762	3.2	2.8	6	15.84	12.64	9.84
B7	GQ-BH1	12.9988	80.23768	2.8	3.7	6.5	14.4	11.6	7.9
B8	CQ-BH7	12.99532	80.23664	4	2	6	13.5	9.5	7.5
B9	CQ-BH8	12.99542	80.2367	4.1	1.9	6	13.6	9.5	7.6
B10	BQ-BH9	12.99604	80.23743	4	2	6	13.7	9.7	7.7
B11	BQ-BH10	12.99618	80.23745	5.1	1.9	7	13.7	8.6	6.7
B12	NAB-BH1	12.99256	80.2303	1	4.5	5.5	14.9	13.9	9.4
B13	NAB-BH2	12.99275	80.22992	1.5	5.5	7	14.9	13.4	7.9
B14	NAB-BH3	12.99279	80.23012	1.5	7.5	9	14.9	13.4	5.9
B15	NAB-BH4	12.99358	80.2305	2	8	10	13.4	11.4	3.4
B16	NH-BH5	12.99239	80.23003	1.2	7.8	9	14.9	13.7	5.9
B17	GH-BH1	12.98955	80.23443	3	6	9	10.97	7.97	1.97
B18	GH-BH2	12.98926	80.23449	2.7	6.3	9	11.88	9.18	2.88
B19	GH-BH3	12.98891	80.23488	2.5	6.5	9	11.58	9.08	2.58
B20	MH-BH1	12.98671	80.24033	0.6	4.1	4.7	9.44	8.84	4.74
B21	MH-BH2	12.98662	80.24011	0.8	3.3	4.1	9.75	8.95	5.65
B22	MH-BH3	12.98674	80.24005	0.6	3.4	4	10.36	9.76	6.36
B23	MH-BH4	12.98662	80.24004	0.5	3.5	4	10.05	9.55	6.05

4.1 Soil Profile Generation

The depth to rock information has been used to prepare the rock depth map by using the interpolation technique for the IITM campus. The rock depth information along with latitude and longitude of the boreholes is given as input to the ArcMap. Further, the top level elevation of the rock layer in each borehole is used in the GIS to develop the soil-rock interface map. The variation of depth to soil-rock interface is shown in Figure 2. It is seen from the figure that the depth to rock layer varies from 2 to 8 m in the IITM campus. The kriging technique is used to develop the soil-rock interface surface from the borehole data. The elevation of the rock soil interface gives the interpolated soil-rock interface surface for the entire campus. The average elevation of the campus is 15 m. The 2D model of the interpolated soil-surface is created in another extension of ArcGIS called ArcSCENE and is depicted in Figure 3.

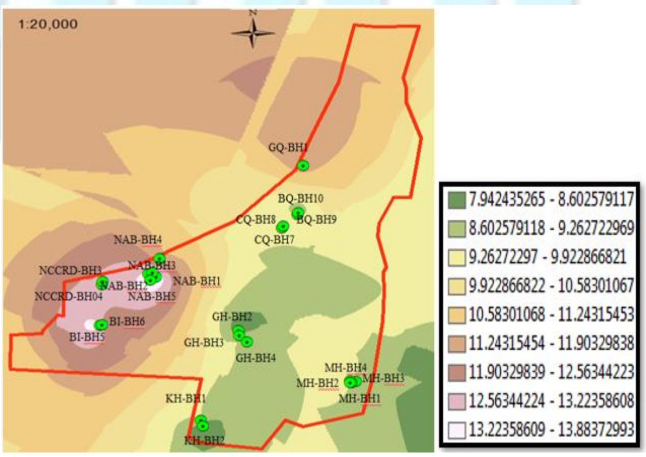

Figure 2. Kriged soil–rock interface

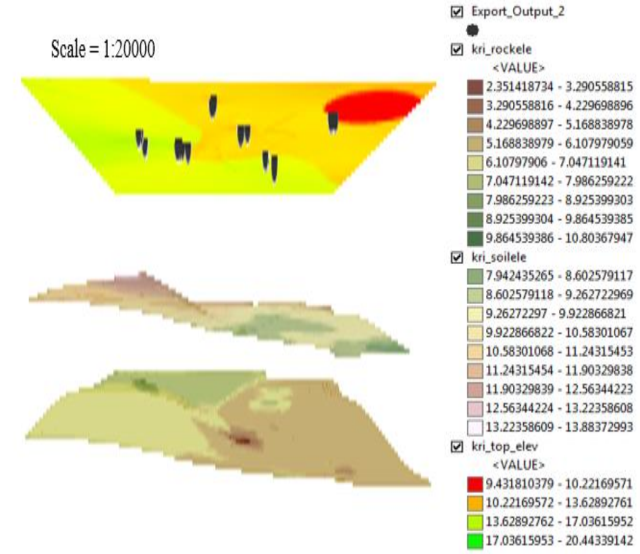

Figure 3. Maps of ground surface elevation, soil and rock

5. Soil Layers From MASW Tests

The MASW test has been used for the evaluation of shear wave velocity, identification of subsurface material boundaries and spatial variations of shear wave velocity. About 12 one-dimensional MASW test survey lines have been identified and accordingly the tests have been carried out. Figure 2. shows all these survey lines [5, 8]. The 1D shear wave velocity results were analyzed at different depths – 1.5 m, 3.75 m, 6.75 m and 10.5 m from the ground level. All the testing locations are georeferenced. These results are imported into ArcMap and kriging is used to predict the shear wave velocity profile for the entire campus. The interpolated shear velocity surfaces are shown in Figure 3 with different color codes. The shear wave velocities are averaged for the top 30 m of the layered soil shear wave velocities and then a map is developed (Figure 4). The 2D shear wave velocity layer model is interpolated from the above results and the different surfaces are created in another extension of ArcGIS called ArcSCENE and the same is depicted in Figure 5.

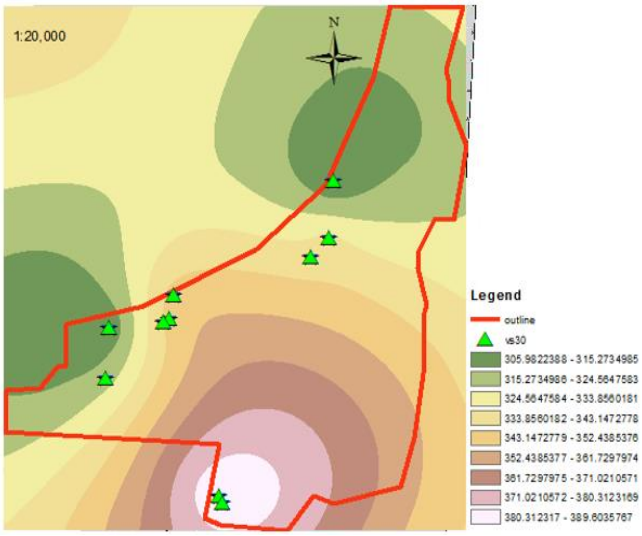

Figure 4. Average shear wave velocity for the top 30 m depth

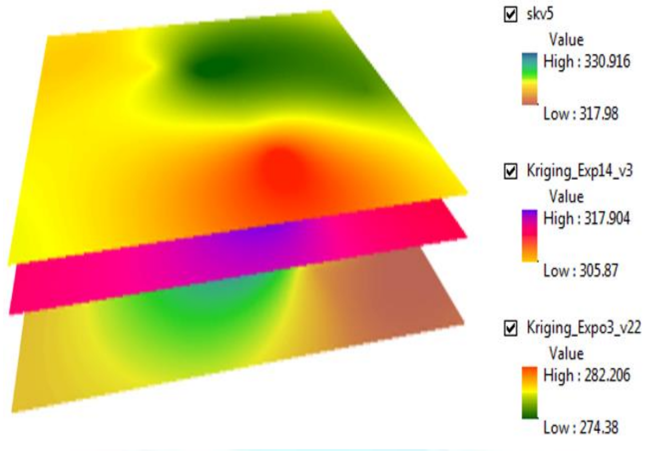

Figure 5. Mapped 2D shear wave velocity layer models at different depths for the IITM campus

6. Conclusion

The results of 1D and 2D MASW tests have been used in this paper for the development of shear wave velocity layers at different depths for the entire IITM campus. The IITM map is georeferenced before developing the subsurface profiles. The kriged profile maps showing different shear wave velocities have been estimated for 1.5 m, 3.75 m, 6.75 m and 10.5 m depths. The spatial variability of shear wave velocity profiles at different depths are developed. The average shear wave velocity map for the campus is developed from the shear wave velocities of the layers within the top 30 m of the overburden. The developed V_s^{30} map is used for soil classification as per the NEHRP classification guidelines and the IIT Madras soil can be classified as “site class D”.

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