CONSTRUCTION AND APPLICATION OF A GEOTECHNICAL DATABASE FOR PREPARATION OF ENGINEERING GEOLOGICAL MAPS FOR NORTHWESTERN IRAN

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Abstract : A geotechnical database has been developed to act as a system for management tool for site investigation data. The system runs on a microcomputer and is capable of producing several sets of geotechnical maps and cross sections.

The resulted analytical maps, clarify those factors, connected with soil features and their geotechnical nature which are of interest to engineers and planners for preliminary site evaluation.

The engineering geological maps have the advantage that every one can give his/her own personal interpretation using such a map.

The paper describes the database system and provides some of its applications in illustration of horizontal and vertical transition of lithofacies, modeling of groundwater flow, maps of *N* value and lithology in the horizontal plane for arbitrary depths, vertical changes of *N* values and lithology data, preparation of subsurface cross sections, dominate frequency analysis of the ground shake and cluster analysis of *N* values data.

Key Words : Database, Engineering geological maps, Lithofacies, Groundwater, *N* value, Cluster analysis

INTRODUCTION

Data are facts, represented by characters, numbers or symbols which carry meaning in a certain context. Computer programs direct and manipulate data within a computer system (Bellotti et al. 1991).

The uses of computer for the management of geotechnical data have been involved in a number of steps over the past 20 years (Bottino and Civita, 1986).

Boring data which are the main obtainable data during site investigation give significant information about subsurface conditions. If this information is systematically managed in a form of engineering geological maps, it can be used as vital tools for preliminary site evaluation.

It is rarely practical from a cost-benefit point of view to compile sets of derivative maps by hand. To assist the input of geotechnical information in to the planning processes at a regional scale, the geotechnical information is summarized into a computer database for the production of engineering geological maps. Review of literatures reveal much effort for data and information management during last three years, i.e., Walters and Liroyd (1985), Chaplow (1986), Hayashida, et al. (1988), Nakayama, et al. (1990), Bently and Stenning (1990), Coulthard, et al. (1990), Forster (1990), Herbschleb (1990) and Zong and Fang.

In this paper, a database system is introduced for management tools of a vast quantity of diverse geotechnical data. The purpose of the developed database is the administration, management and presentation of borehole logs in forms of engineering

geological maps using a computer system. The aim is to explore new, faster, better or cheaper ways of making predictions in engineering geology.

In this task the system is used to clarify the regional geotechnical characteristics of Gilan plain. The aim is to reveal subsurface conditions in the area and to estimate vibration property of ground for earthquake.

STUDY AREA

The study area is located in the Northwestern part of Iran, south part of Caspian sea (Gilan plain).

The relief of the area is very marked and a range of altitude from 28 meter below mean sea level on the Caspian shore to the more than 3300 meter on the Agh Dash is encountered.

The Caspian depression is occupied by sea in the Northeast and by alluvial and coastal sediments on the Gilan plain. The depressed area is clearly of tectonic origin and the natures of the hill front to the West suggest that its limits may be determined by extensive faults which are now buried beneath the sediments of the coastal plain (Davies, Hamzepour, et al., 1975).

Geological map of the study area is illustrated in Fig.1. Recent deposits of the Caspian plain occur mainly as a belt of marine alluvium adjoining the coast and as deltaic deposits of rivers flowing into the Caspian sea. Pleistocene deposits, partly marine and partly fluvial or deltaic in origin, form terraced and outcrops further inland rising to about 200 m.

Fig.1. Geological map of the study area

The highest deposits occur at about 220 m and are preserved as a small patch of sand and gravel resting on Carboniferous phyllites about 17 km South of Rasht. The present - day beach deposits consist largely of sand. The younger Quaternary terrace features of the Caspian littoral are severely disrupted by the Sefid Rud delta and other smaller rivers to the east. Most of the lower terraced deposits, which are regarded as having accumulated under the influence of Caspian sea level, rest on irregular surface of Neogene rocks(Annells, 1991).

The area suffered a catastrophic earthquake in 1990. As the area is located in one of the most hazardous seismic zones of Iran and subsurface materials are weak, for re - construction procedures in the area engineering geological evaluation is considered as a vital tool for planners and engineers in this respect.

DATABASE SYSTEM

The database system is managed to be capable to store and manipulate borehole logs which include geotechnical information. The overall concept of the system depends upon creation of a series of data files, each file containing all site investigation information of an individual borehole.

There are programs to allow information to be entered into the files, for correction of stored data, also

different types of engineering geological maps can be produced from the stored data using retrieval programs. The data file for each individual borehole has a fixed format to allow random access to it and comprises different parts to hold the variety of the data required.

Fig.2. Configuration of the hard in current use

The system is mounted on a microcomputer and the retrieval programs are written in the BASIC language. The hardware for the geotechnical database consists of a microcomputer with 1.5 Megabytes of random access memory (RAM), a 40 Megabytes hard disc drive, a RGB color graphic screen, a digitizer, a color printer, and an X - Y plotter (Fig.2).

DATA PROCESSING

The geotechnical information from 154 site investigation reports was assembled from borehole record collections. The reports contain a total of more than 400 pit and borehole logs mostly up to 10 meters depth from which geotechnical data were extracted. Old borehole data or badly written reports were rejected. For each borehole the following information was stored into the computer database.

- 1) Borehole name, latitude, longitude, and altitude of boring site.
- 2) Groundwater level in the borehole.
- 3) Lithofacies information: depths to the bottom of each unit, the coded soil name.
- 4) Geotechnical test results: such as N value of standard penetration test, density, moisture content, atterberg limits, and particle size distribution.

Due to diverse type of soil parameters, in this study only lithofacies and N value data were selected for analysis. Obviously the same kind or similar analyses can be applied for the other parameters easily.

In order to have better image from borehole loca-

tion, at first some of the main features of the study area such as seashore, location of the main rivers, were traced using a digitizer and the information were entered into the computer.

LITHOFACIES ANALYSIS

The subsurface soil types (particle size) control geotechnical characteristics of the superficial layers. Thus soil type can give some initial impression of soil behavior such as its permeability, potential of stability, etc.

The primary aim of the collection of site investigation data is to construct a local stratigraphy of the superficial deposits in relation to the engineering project planned.

The constructed database system can be used to reveal a superficial deposit's lithology in the horizontal plane for arbitrary depths or elevations which are significant from geotechnical and stratigraphy point of view respectively. The map can be made at every required depth or elevation in the subsurface. A simple lithological description of the layers (i.e. Gravel, Sand, Silt, and Clay) was considered to be the output result.

For example the retrieval of lithology at the depths of 5 meters and 15 meters are performed to identify superficial conditions in the Gilan area (Figs. 3,4). Clearly sandy and silty soils are accumulated at 5 meters depth in Lahijan and Anzali area, while Rasht area mostly is covered with clay type of soils. Distribution of sandy and silty soils in the Lahijan

Fig.3. Distribution of lithology at depth 5 meter in the subsurface of Gilan plain

Fig.4. Distribution of lithology at depth 15 meters in the subsurface of Gilan plain

Fig.5. Modeling of the groundwater flow as produced by the trend surface analysis

and Langroud area might be attributed to the abandoned bed of Sefid Rud river. At depth 15 meters, distribution of clay deposit in the Lahijan area also increases. This might be related to the changes of the Caspian sea level. Paleogeographical interpretation may be performed by comparison of the lithology at the same elevation.

MODELING OF THE GROUNDWATER FLOW

The groundwater level of the boreholes stored in the database were used for modeling of groundwater flow.

For modeling of groundwater flow, the method proposed by Koike, et al. (1990) was applied. Groundwater level faces to the seasonal fluctuations. The rate of fluctuations varies with respect to the time and locations. To overcome these problems, the water table is assumed to be smooth in area then the polynomial surface analysis can be used for groundwater modeling.

The equation for a polynomial surface of m th-order has the form:

$$f(x, y) = \sum_{r=0}^m \sum_{k+l=r} a_{kl} x^k y^l \quad (1)$$

Where:

$k, l : 1, 2, \dots, m$

a_{kl} : Coefficients calculated using the least squares method

In weighted least squares the following expression should be minimized.

$$S = \sum_{i=1}^m w_i \{z_i - f(x_i, y_i)\}^2 \quad (2)$$

Where:

w_i : the weight assigned to the i th datum Z_i

n : is number of data

Koike, et al. (1990) regarded the weight w_i as the inverse fluctuation range of the water table in a year at the point (x_i, y_i) , but in this study the weight is 1.0 for all the data.

Optimum order of the polynomial trend surface can be determined from the value of AIC (Akaike's Information Criteria) (Akaike, 1973).

$$AIC = n \log_e 2\pi + n \log_e Q + n + 2(C + 1) \quad (3)$$

Where:

Q : the deviation of the residuals.

C : the number of coefficients used in the polynomial surface.

The polynomial surface which minimizes the AIC is regarded as the best model to characterize the regional trend in the data.

When the polynomial surface is identified, the maximum slope (gradient) R_i through the point (x_i, y_i) on the surface and its orientation α_i are given as follows:

$$R_i = \sqrt{\left\{ \frac{\partial f(x, y)}{\partial x} \right\}^2 + \left\{ \frac{\partial f(x, y)}{\partial y} \right\}^2} \quad (4)$$

$$\alpha_i = \tan^{-1} \left\{ \frac{\partial f(x, y)}{\partial y} / \frac{\partial f(x, y)}{\partial x} \right\} \quad (5)$$

Assuming uniform permeability for the aquifers in the area, R_i and α_i are considered as gradient of water flow and its direction at the point (x_i, y_i) respectively.

The result of modeling is shown in Fig 5. The polynomial surface of third order minimizes the value of AIC.

It can be understood that in general groundwater flows from the plain toward Caspian sea. Groundwater in the central parts (Rasht area) move toward north part, and is discharged into the sea near Mordab Anzali. Also it can be interpreted that, Sefid Rud in some locations recharge the groundwater and in some parts the groundwater is discharged into the Sefid Rud river.

GEOLOGICAL AND GEOTECHNICAL CROSS SECTION

The compilation of field recorded data into logs and replotting of the data for drawing cross sections is a critical part of any site investigation.

The database system can be used for preparation of any arbitrary subsurface cross section. The user can choose any optional cross section using a mouse on a graphic screen to produce fence diagrams which involve the logs of boreholes located at a certain distance from the cross section line. No interpolation is involved as the diagram represent user nominated sequence of boreholes.

Fig. 6 shows a cross section from north part of Lahijan to the south part of Bandar - e - Anzali for the investigated area which is drawn from Lahijan to the Northwest of the area. The cross section clarifies distribution of sandy soils in the Lahijan and its transition to the clay type of soils in the Northwestern part of the area.

N VALUE ANALYSIS

The number of blows per foot, namely N value, is a valuable indicator for illustration of ground resistivity against penetration. It can quite closely calibrate against the angle of shearing resistance and against Terzaghi's bearing capacity factors N_q and N_c or density of the superficial layers.

1. Horizontal and vertical distribution of N values data

Due to significance of N value as an engineering parameter for evaluation of superficial resistivity, it is valuable to construct maps on the basis of this parameter. The developed system is capable to perform maps of N values and lithology in the horizontal plane

Fig.6. A cross - section from the study area

for diverse depths, which also can be repeated at any desirable depth or level in the subsurface. Figs. 7 and 8 are examples of such kind of maps, which indicate that in general the subsurface of the area at the depth 5 meters consists almost entirely of unconsolidated deposits. By increasing the depth N value also increases in the central and eastern parts of the area.

In geotechnical boreholes N values data usually are not available for 1.0 meter interval for all of the depths. For preparation of N value maps and also for clustering of the N values data, the lithology of the upper and deeper layers having N value were considered to interpolate the N value for the desired depth. For this purpose one of the following two lithological patterns were considered.

- 1) For a desired depth which the N value is unknown, if the lithology of the upper and deeper layers having N values are identical, linear interpolation based on the two N values is performed.
- 2) If the lithology of the upper and deeper layers are different from each other, the N value of the layer having the same lithology is used as the one at the desired depth.

2. Foundation Strata

In general a stratum having N value of 30 or higher with at least 3 meters thickness is considered to have feasible conditions for foundation of major buildings. The depths to the top of such a stratum and its lithology are also obtainable from the database easily. Fig.9 illustrates the location of the boring and the depth of the strata that satisfies the above men-

tioned conditions. It is clear, such subsurface layers are very few, but in the location which the conditions exist the foundation strata are very shallow (5 to 10 meters depth).

3. Dominate frequency analysis of the ground shake.

In major buildings design, earthquake-proof consideration is usually taken based on the dominant frequency of the ground shake at the building site. The frequency is determined through the microtremor measurement at the site and the spectral analysis of the data. The database is also applied to estimate dominant frequency of the ground shake. For this purpose, the shear wave velocity V_s was calculated using the following empirical equation which is obtained for typical fine grained soils in Japan.

$$V = 85.34\bar{N}^{0.348} \tag{6}$$

where $\bar{N}$ is the average of N vales of the first layer (the layers which overlie the foundation bearing strata).

Dominant frequency F_o is then may be estimated by the quarter of wave length.

$$F_o = V_s / 4H \tag{7}$$

where H is the thickness of the first layer. The results of the calculated dominant frequency is presented in Fig 10. It is clear that the calculated dominant frequency for the area are mostly higher than 4.0, and it increase toward south part of the area.

Fig.7 N value rate at depth 5 meter in the subsurface of Gilan plain

Fig:8 N value rate at depth 15 meter in the subsurface of Gilan plain

Fig.9. Depth up to the top of the foundation bearing strata

Fig.10. Dominate frequency map of the ground shake, estimated from the *N* values data

4. Clustering of N values data

In order to find out about the similarities of vertical changes in geotechnical properties of the subsurface layers, cluster analysis was applied. N value as a parameter which is affected by the lithofacies characteristics of subsurface layers was used. For this purpose N values and their vertical changes up to 15 meters depths at 1.0 meter intervals were utilized. For clustering of N values data we have used ordinary Euclidean distance. Let r and s be two boreholes with p variables (here p is the N value from surface to depth 15.0 with 1.0 meter interval, thus it is 15). The two boreholes can be defined as the following vectors.

$$Xr = (x_{r1}, x_{r2}, \dots, x_{rp}) \quad (8)$$

$$Xs = (x_{s1}, x_{s2}, \dots, x_{sp})$$

The Euclidean distance between the two boreholes is defined as

$$drs^2 = \sum_{k=1}^p (x_{rk} - x_{sk})^2 \quad (9)$$

Where drs is the distance between boreholes s and r .

The Ward's agglomeration method was used for clustering. The result of clustering is given in Fig.11. Number of cluster was decided to be four. Fig.12 illustrates the features of each of the cluster which obtained by averaging the N value data belonging to each of the clusters. Most of the borehole data locate in the second and third groups which shows slight increases of N value with the depth. Borehole of the Lahijan area almost locate in the second group. This group is characterized by low N value rate compared to the other groups. Considering high groundwater level in this area and low N value rate, it might be the main factors for occurrence of liquefaction in this area during the earthquake. The liquefied area during the earthquake has a good agreement with cluster 2.

CONCLUSION

A database system for management of site investigation data have been developed. The system is capable of producing several sets of engineering geological maps. The system was applied to reveal the subsurface characteristics of Gilan plain in North-western Iran. Different types of maps such as lithofacies and N value changes, Groundwater flow modeling,

Fig.11.Cluster analysis of the N values data

Fig.12. Average of N values for each group

etc were produced.

The results showed that the area is mostly under-lined by fine grained soils with poor geotechnical features. There was a good agreement between liquefied area during the earthquake and the zone which is located in cluster 2 using cluster analysis. Also groundwater flow was estimated for the area.

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