11-11-nn

Доклади на Българската академия на науките
Comptes rendus de l'Académie bulgare des Sciences

Tome 69, No 11, 2016

GEOLOGIE

Géologie del'ingénieur

GEOLOGICAL ENGINEERING MODEL FOR QUATERNARY DEPOSITS IN ISFAHAN CITY, IRAN

Rasool Dadkhah, Mohammed Ghafoori, Gholam Reza Lashkaripour, Nasser Hafezi Moghads

(*Submitted by Academician I. Zagorchev on May 17, 2016*)

Abstract

The present paper examines the sedimentary environment and geotechnical features of Quaternary deposits in Isfahan City, Iran. The study divides the sedimentary deposits into five zones on the basis of geological, geomorphological, sedimentological, hydrogeological, and geotechnical data. The zones are as follow: the alluvial fan zone (AFZ), upper clayey zone (UCZ), lower clayey zone (LCZ), river channel gravel zone (RCGZ), and river channel sandy zone (RCSZ). The geotechnical characteristics of each unit were considered to determine and evaluate potential geological problems in Isfahan. The results showed that UCZ is generally the least stable zone and AFZ is the most stable zone for construction and development of civil projects. This model also enables a better design of field surveys as well as optimal selection of geotechnical investigation techniques for future civil projects.

Key words: geological engineering model, geotechnical characteristics, Quaternary deposits, sedimentary environment, Isfahan

Introduction. The study of geological engineering of Quaternary sedimentary deposits must include geological, physical, mechanical and chemical features of the deposits, underground water, and potential problems for proper programming and decision-making for construction of civil projects on Quaternary deposits [1]. Problems have arisen over the years because insufficient attention has been focused on subsurface conditions for civil projects. It has been determined that comprehensive identification of the geological characteristics of these deposits as they relate to engineering is required for optimal performance of projects on Quaternary deposits. Most current civil projects on Quaternary deposits require comprehensive geological studies [2]. Urban geology, including information about civil engineering environments, is a basic requirement for programmers and engineers of civil projects studies [3, 4]. In most parts of the world, urban geology is considered to be environmental geology which is essential for determining potential problems during urban development [5–7].

A geological engineering model is a proper solution for solving engineering problems in civil projects by estimation of the mechanical and physical properties of deposits [8]. An early geological engineering model was introduced by Morgenstren and Cruden [9]. Stapledon explained a geological engineering model and identifying the key point that the engineering geological model should be based on "an understanding of the regional geology, geological history and detailed site geology described in terms that are quantitative related to engineering requirements and understood by both geologists and engineers" [1, 8]. Scientists offer geological engineering models to explain the surrounding environment. Sullivan [11] suggested the term "geological model" and stated that providing a model for each civil project is necessary for quality control and to determine geological issues. Scientists have classified and provided geological engineering models based on the sedimentary environment, geomorphology, hydrology, and other geological parameters.

The research area of the current study includes the historical part of Isfahan City, which is a major metropolis in Central Iran. The catchment area for Zayandehrud River is located in the middle of the Iranian plateau at $50^\circ 2''$ to $53^\circ 24''$ E longitude and $31^\circ 11''$ to $33^\circ 42''$ N latitude. The area of this basin is about 41 550 km^2 and the average elevation is 2514 m. Zayandehrud is the only permanent river in this catchment area. The aim of this paper is geological model for the Quaternary deposits under Isfahan City. It provides a geological engineering model to be used for developmental plans and studies in the city. Field zones having similar features have been classified according to geological, geomorphological, and sedimentological studies. The large amount of data collected for this study from various geological and geotechnical reports has been compiled to determine the mechanical and physical features of the deposits and potential problems facing engineering projects in each zone. Although the information from these zones and the model are not helpful in understanding the details of the soil layers, the model can be useful for prediction of geological engineering conditions and geological hazards to performance of future civil projects in the region.

Geological and morphological framework. Isfahan City is located in central Iran in which Jurassic, Cretaceous, and Quaternary formations have been observed [12]. The oldest protruding rock formation is a thick sequence of shale, siltstone, and dark gray sandstone that contains traces of plant fossils. Jurassic formations containing shale and sandstone have surfaced in the southern and eastern parts of Isfahan and can be observed. Cretaceous formations have surfaced along with red sandstone at the base with a purple layer of conglomerate. Alluvial Quaternary formations located in Isfahan comprise foothill alluvial sediment and river deposits. Geomorphological factors should be considered during interpretation of geological maps [13, 14]. Area of Isfahan City can be morphologically classified into four zones: plains, hills, alluvial fans, and mountains.

Sedimentological framework. The main sedimentary environments in Isfahan are alluvial fan zones and river zones. Sediments of northern alluvial fan gradually change into river sediments. River sediment has developed in all parts of the city, particularly in the central and northern areas. The fine-grain river sediment environment lies on the surface in these central and northern areas with coarse sediments from the river channel below on an even lower deposit of fine-grained sediment. Alluvial fans dominate mostly in the region, particularly the active tectonic regions. The repeated alteration of this sedimentary environment from polar regions to tropical wet regions has made this environment a focus of much research [15, 16]. Alluvial fans are versatile areas that provide topsoil sources for civil projects and are good locations in which to store underground water in dry regions. The alluvial fan sediment resulting from erosion of shale and limestone formations cover the Jurassic rock deposits in some parts of the city (Table 1).

Hydrogeological framework. Groundwater and aquifer distribution in the area have been determined throgh geophysical and hydrogeological studies by the Isfahan regional water authority. The depth of the ground water varies from 0.5 m in the southern parts of Isfahan to more than 40 m in the northern section of the region. Main direction of water flow is toward north and northeast. Isfahan area has two aquifers featuring different transmissivity and available channels that can affect civil projects. The main source of groundwater, both directly and indirectly, is Zayandehrud. The aquifer formed from coarse sediments around the river is highly permeable. Fluctuations in water level in this aquifer is a function of fluctuations of water level in the river bed. The depth of this aquifer gradually decreases toward the north and northwest and finally disappears completely to the northwest. The aquifer formed of alluvial sediments with a surface area of bedrock developed in the southern parts of the city has very low transmissivity. Groundwater level is primarily affected by the work of irrigation wells and it is not related to the river fluctuations. Groundwater gradient in the alluvial sediments is about 35 per 1000.

Result and discussion. ***Geological engineering model of Isfahan. Geotechnical properties of sediment.*** Determination of alluvial deposits is required for civil projects and to ascertain the safety and stability of the region. One initial stage of studying and planning civil projects is to develop an understanding of the physical and mechanical properties of the soil. The parameter of shear strength relates to the type and amount of clay minerals in the soil, shape and size of the particles, particle arrangement, forces between the clay particles, and the chemical makeup of pore water [12]. The Isfahan city sediments have

Table 1

Lithofacies definition, description and interpretation sediment in the Isfahan city (Based on Miall (1978, 1996)

Facies code	Definition	Structure	Description	Interpretation
Gmm	Matrix-supported massive gravel	Massive	Matrix-supported, very weakly stratified, poorly sorted, ungraded cobble pebble gravel composed of sandstone, shale and limestone. clasts showing angular shape	Plastic debris flow (high-strength, viscous) in first parts of alluvial fans deposit
Gmg	Matrix-supported graded gravel	Normal to reverse grading	Matrix-supported, weakly stratified, poorly sorted, poorly graded cobble pebble gravel composed of siltstone, sandstone, shale and limestone. Clasts showing angular shape fabric	Viscous and pseudo-plastic debris flow alluvial fans deposit
Gcm	Clast supported gravel	Massive	Clast-supported, massive, poorly sorted, poorly graded pebble gravel composed of siltstone, sandstone, shale. clasts which are angular to subangular	Pseudo plastic debris flow alluvial fan (inertial bedload, turbulent flow) deposit, wedge shaped and channel shaped
Gm	Clast supported gravel	Massive to thin bedded	Clast-supported, Massive to thin bedded, well sorted, well graded sand and gravel which are rounded	rapid mass deposition with flooding, High-energy flow
Gh	Clast supported gravel	bedding	Clast -supported, bedding, well sorted, well graded sand and gravel which are rounded, with imbrication	rapid mass deposition with flooding, High-energy flow
Sm	Massive sand	Massive	Massive or faint lamination	Gravity flow deposits on flood basin, some times with flow turbulence
Sp	Cross-bedding sand	Cross-bedding	Tabular cross-bedded or lamination, herringbone cross bedded, reactivation surfaces	Grouped tabular sets with bimodal paleocurrents that represented tidal channels, ripple or 2-D dunes
Fm	Massive clay/mud	Massive	Massive, dark grey to dark brown and red clay or mud with organic material	Overbank deposit, abandoned channel deposit
Fl	Ripple laminated silt or planar laminated silt, mud or clay	Ripple laminae, planar laminae	Ripple laminated yellow to brown silt, or thick bedded to thinly laminated grey to yellowish brown silt or clay or mud	Sheet flooding and suspension settiling of overbank fines

been geotechnically characterized by testing done in situ or in the laboratory on undisturbed and disturbed samples taken from depths of 0 to 40 m according to ASTM recommendations. Most data was obtained from existing geotechnical reports; the remainder was obtained from boreholes, trial pits, and testing (Fig. 1).

Southern section. ASTM classification determines that the alluvial deposits in the southern section include a gravelly group (GM, GC). The dry density of the gravelly deposits in this section was higher than that of other sediment and attained 2.38 g/cm^3. The high percentage of this parameter is related to the sedimentation environment and the distribution of particles of various sizes. The plasticity properties (LL, PL, and IP) equal those for fine-grain particles in this section and indicate a high clay content. The liquid limit of fine-grain sediments varies from 23% to 49% and their plasticity index varies from 9% to 25%. The standard penetration test (N_{SPT}) for soils > 50 blow counts for this section.

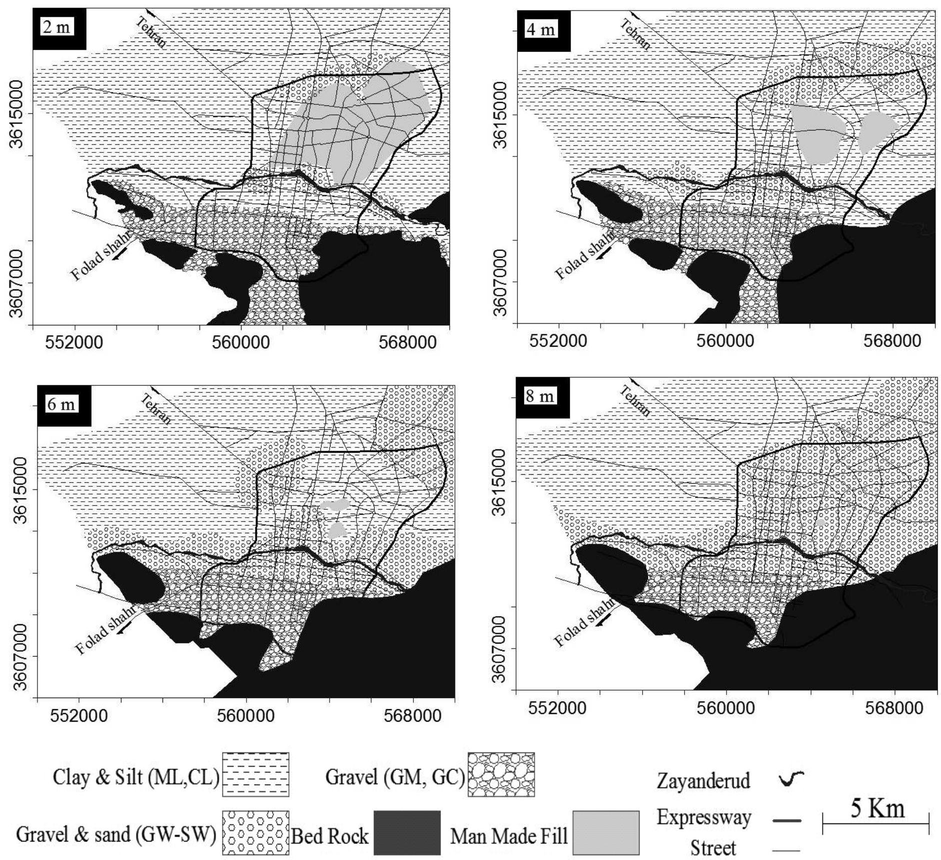

Fig. 1. Geological plan based on data from geotechnical boreholes

The reason of these results is the high soil density and the distribution of coarse particles in the deposit. The mechanical parameters (internal friction angle) are relatively high. This results from the high percentage of fine-grain clay particles in the deposits of this sedimentary environment (Table 2).

Central and northern sections. The unified classification of deposits in the central and northern sections of Isfahan comprise a gravelly group, sandy group low plasticity fine-grained group and high plasticity fine-grain group. The dry density of the gravelly group in this environment is higher than those in other sediments and on average is 2.14 g/cm^3; that of the fine-grain group is lower at 1.67 g/cm^3. The coarse group is mostly non-plastic and the fine-grain group shows high levels of plasticity (Table 2).

Geological engineering model of the study area. A variety of geological models have been developed for most civil projects mostly in the recent years [17–20]. An engineering geological model based on studies and considerations can help the urban development. Engineers should take decisions and offer effective plans using the information obtained from an accurate geological model. Information such as the physical, mechanical, and chemical properties of the soil gain importance and rapid and simple access to such data is very important. The purpose of a geological model is to describe sedimentation and features of the sedimentary deposits of a region. In parallel with development of civil structures, geological engineering models draw attention to the components of optimal operation of structures. Geological engineering models of sedimentary data offers a proper model of subsurface conditions to determine the best conditions for macro-programming projects. A geological model is required to understand the geological conditions of the Isfahan region. Sedimentary environments in Isfahan include alluvial fan, river channel gravel, and floodplain zones. The formation of these deposits differs from other deposits and their development differs under the surface and by depth. Alluvial fan zones developed in the southern sections and are replaced by river sediment in the central sections. The central and northern sections of river sediment include river channel and floodplain sediments (Fig. 2).

Problems with Sediment in Isfahan. The problems predicted in engineering geology are important for land-use programming and play a role in macro-decision-making. The problems in the study region differ for rock and alluvial deposits. Southern regions of Isfahan with rock outcrops require study to determine the instability of hillsides, presence of crushed areas, and the dip and dip direction of discontinuities. The geotechnical study found man-made fill, expansive soil, and collapsible soil in Isfahan City area (Fig. 2).

Man-made fill. The great age of the city of Isfahan means that man-made fill and construction waste are present in different thicknesses and development. In the central sections, the thickness is greater than 8 m. The presence of an ancient cemetery currently located at a depth of 5 m was confirmed during geotechnical studies. The soils are highly compatible because of the heterogenic distribution

T a b l e 2

Physical and mechanical parameters of deposits of Isfahan city

Parameters	central and northern				southern
	Gravely Group	Sandy Group	Lower Fine-grain group	Upper Fine-grain group	Gravelly group
UCSC	**GW-GM-GC, GM,GC**	**SW-SM, SW-SC, SM, SC**	**CH, CL**	**ML-CL ML**	GM, GC
Physical parameters					
Fine-grain percentage (F.C.%)	6–19 14.5*	12–45 25*	77–91 85*	57–98 85*	12–38 20*
Plasticity LL	NP-28.9 15*	41–59 51*	NP–16 10*	23–49 40*	23–49 40*
Plasticity PI	NP-12 8*	18–32 25*	NP-16 10*	9–25 16*	9–25 16*
Dry density (g/cm^3)	2.02–2.24 2.14*	1.7–2.23 2.00*	1.51–1.83 1.67*	1.52–1.98 1.75*	1.85–2.36 2.13*
Mechanical parameters					
SPT (N_{COR})	19–50 40*	10–48 32*	9–41 29*	5–39 24*	> 50
C(kPa)	3.92–10.78 5.88*	4.90–11.77 6.86*	37.26–145.1 93.16*	18.63–121.6 61.78*	12.47–20.59 17.65*
φ **(deg.)**	28–32 30*	24–30 27*	12–23 18*	11–18 14*	28–32 30*
C'(kPa)	0.0–3.92 1.96*	0.0–4.90 2.94*	13.72–109.8 57.85*	14.7–56.87 30.4*	5.88–8.82 7.84*
'φ(deg.)	29–33 30*	27–32 29*	21–29 25*	20–28 24*	31–36 33*
E_S(MPa) Natural Moisture	300–450 375*	95–175 130*	150–300 220*	300–850 450*	300–850 450*
E_S(MPa) Saturation	24.5–39.2 29.4*	7.8–15.2 10.8*	11.8–24.5 17.6*	19.6–39.2 29.4*	29.4–58.8 44.2*

*The average parameter

of particles. This fact should be considered when carrying out civil projects; a lack of attention to these soils can cause subsidence at the construction site which could cause irreparable damage (Fig. 2).

Expansive and collapsible soil. Geological and field studies indicate that the collapsible soil exists in the northern sections of Isfahan as shown in Fig. 2.

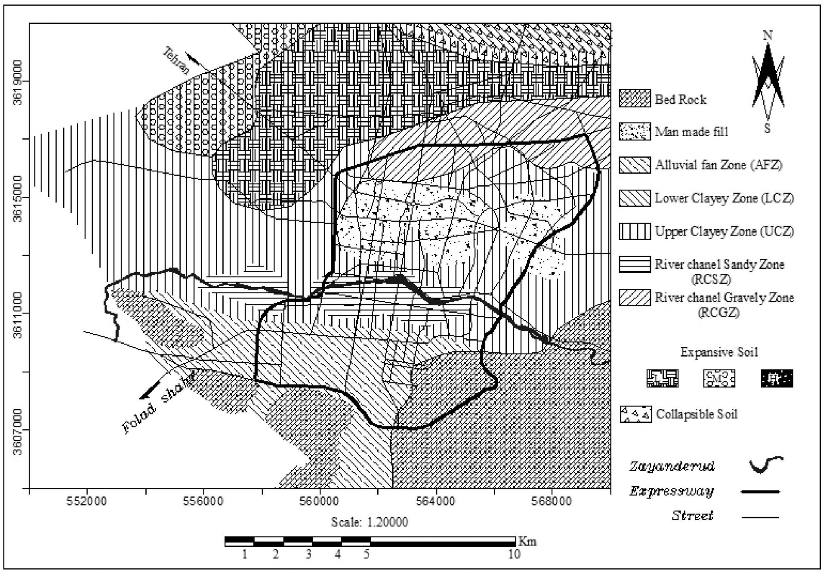

Fig. 2. Distribution of the zones and problems of engineering geology defined in this research

UCZ soils are young and consist of silty and clayey material with low relative density and strength parameters. It can be deduced that these silty and clayey soils in the UCZ have low to moderate swelling potential. Collapsible soil shows volume change during saturation and this change can result in overloading or soil saturation. Structures built on this soil can experience sudden subsidence under the effect of soil saturation or overloading. Determination of the presence of such soil is important. Collapse susceptibility is mainly related to the compressible nature of the clayey soil in the UCZ. Development should be limited over these deposits in the northern sections; the presence of such soil is the result of sheet flooding.

Conclusions. It was determined that Isfahan can be divided into two sedimentary environments: alluvial fans and river channel sediment. The alluvial fan, river channel gravelly, and lower clayey zones offer the best geological engineering properties for construction with no foreseeable problems. Five geological engineering units were identified and introduced in the form of a geological engineering model based on the geotechnical and sedimentological properties of the sediment in the region. The geological engineering characteristics of units were analyzed and their main geological engineering problems identified. Younger zones such as the upper clayey and river channel sandy zones have unfavourable geological engineering properties because they are younger and possible construction problems should be considered before construction on these zones.

Two aquifers with different transferability exist in Isfahan and can affect civil projects. The main feeding source of both aquifers (direct or indirect) is the Zayandehrud River.

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Department of Geology
Faculty of Sciences
Ferdowsi University of Mashhad (FUM)
Mashhad, Iran, 9177948974
e-mail: `ghafoori@um.ac.ir`