The addition of geotechnical properties to a geological classification of coarse-grained alluvium in a pediment zone

A. Fakher[1], A. Cheshomi[2] & M. Khamechiyan[2]

[1]Tehran University, Civil Engineering Faculty, PO Box 11365-4563, Tehran, Iran (e-mail: afakher@ut.ac.ir)
[2]Tarbiat Modarres University, Engineering Geology Department, Tehran, Iran

Abstract

The city of Tehran is founded on Quaternary alluvium, which has been geologically classified by Rieben. The city is located at the foot of the Alborz Mountain Range, which is basically composed of Eocene pyroclastic deposits (green tuff) and other volcanic rocks. The geology and the morphology of the Tehran region is similar to that for other cities located at the foot of mountains. Rieben divided the Tehran alluvia into four categories, identified as A, B, C and D (from oldest to youngest). In the Rieben geological classification system, which is widely used in Iran, the age and general geological characteristics of alluvia are considered, rather than engineering properties. The Rieben and other geological classification systems are described in this paper and geological factors that affect the geotechnical characterization of the Tehran alluvium are discussed. Because of the nature of the Tehran soils, undisturbed samples for laboratory testing are difficult to obtain and the execution of large-scale *in situ* tests is difficult, expensive and not practical for the majority of construction sites. Accordingly, a geological–geotechnical classification system is required to assess the engineering properties of coarse-grained soils for use in small to medium-sized construction projects. To determine the geotechnical properties of the Tehran alluvia, a number of *in situ* tests have been undertaken. The test results have been compared with published research results and the Rieben classification system has been extended to cover geotechnical properties. A similar framework could be used to create local geotechnical–geological classification systems of other coarse alluvia in other locations.

The city of Tehran is located at the foot of the southern slopes of the Alborz Mountains Range and sits on an alluvial plain formed over time by flood erosion of the mountains. As a result of this process, large and small particles have settled on high and low elevations, respectively, resulting in varying geological conditions. The source rocks, slope of the mountains and climate conditions are important factors in determining the properties of the soils deposited at the foot of mountains. If the source rock is soft and the slope is gentle, uniform fine-grained soils are created in seismically non-active areas. The Alborz Mountains Range is steep and mainly consists of tuff, limestone and dolomite. The area experiences heavy rains in some seasons and is seismically active. Therefore, non-uniform soil layers have been formed.

Tehran is expanding rapidly and for many of the buildings being constructed the nature of the foundation conditions, posed by the underlying alluvia, is a major consideration. To determine the geotechnical parameters of the Tehran alluvia, it is necessary to carry out geotechnical investigations. For small and light structures, conventional geotechnical investigations can exceed the available budget but shallow investigations can be undertaken by simple low-cost methods. In sand and fine-grained soils, simple equipment such as the Mackintosh probe (Fakher *et al*. 2006) can be used. However, low-cost methods are not widely available for coarse-grained soils and it is necessary to undertake large laboratory and *in situ* tests. Such large-scale tests are inappropriate for small structures and for the preliminary assessment of soils. Therefore, a local geological or geotechnical classification is required. The Rieben (1966) geological classification system is frequently used by local engineers to provide a qualitative geological description of the foundation soils, but the classification is based on the age of the alluvia and does not provide useful information about engineering properties of the soils. A combination of geological information and *in situ* test data could provide the possibility of being able to make a quick assessment of the geotechnical properties of the alluvia.

Geological classification

Rieben (1966) was a European geologist who worked for the Geological Survey of Iran (GSI) in the mid-20th century. His classification of Tehran alluvia is still widely used by local geologists and engineers. Rieben (1966) divided the Tehran coarse-grained alluvia into four categories, identified as A, B, C and D, where A is the oldest and D the youngest. Some simple profiles, produced by the authors to schematically show the sequence of Tehran alluvia formation, are presented in Figure 1 and specifications of these alluvia are presented in Table 1 using conventional terminology. Figure 2

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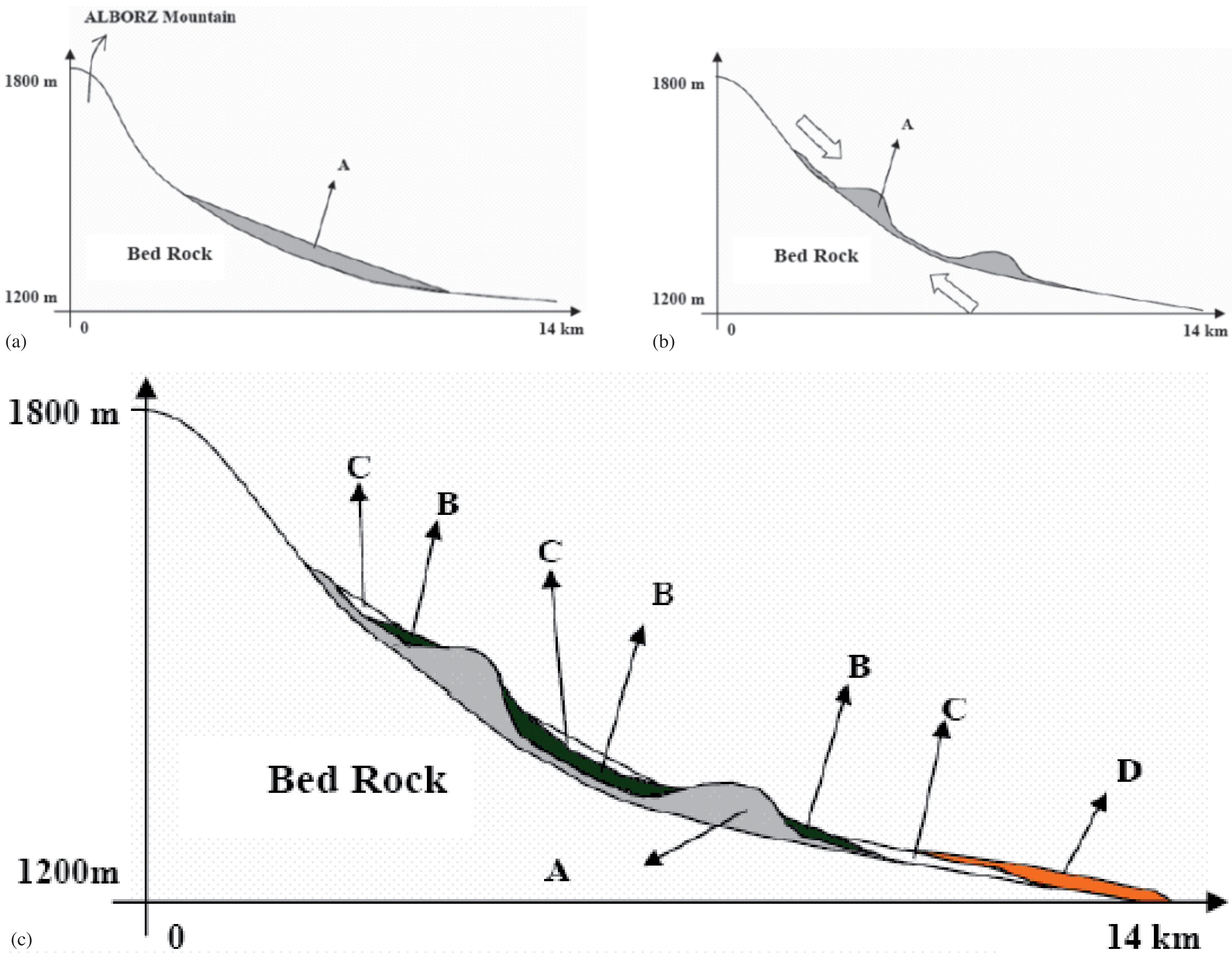


(a) (b) (c)

Fig. 1. Sequence of Tehran alluvia formation. (**a**) Sedimentation of A alluvium about 5 Ma ago. (**b**) Tectonic compression and folding of A alluvium. (**c**) Formation of B, C and D alluvium after folding of A alluvium caused by erosion and sedimentation.

shows some photographs of outcrops of the Tehran alluvia. To date, all research into the Tehran geology has used the Rieben (1966) geological classification and until now this classification has not changed fundamentally (Berberiyan *et al.* 1986). The advantages of the Rieben classification are: (1) it gives a first qualitative assessment of the characterization of alluvium; (2) it recognizes the sedimentary environments of the alluvia; (3) it gives useful information about the age and history of basin sediment.

However, a geological classification does not provide information about engineering properties. This is the major disadvantage of the Rieben classification of Tehran alluvium, with respect to engineering practice. When alluvia are classified based on their age, alluvium in the same category (same age) may have different geotechnical properties. For example, the B and D alluvia in the north of Tehran have coarse grains ranging to very large sizes but these same alluvia in the south of Tehran have fine grains. Consequently, the B and D alluvia in the north and south of Tehran have different geotechnical properties but are in the same geological category.

The Rieben (1966) classification is widely recognized by geologists working in civil engineering projects in Tehran. Therefore, it would be convenient to assess the engineering properties using a modified form of the Rieben geological classification, rather than proposing a new independent geotechnical classification. An adapted geological classification able to address geotechnical characterizations would have the following advantages. It would: (1) ease communication between geologists and engineers; (2) provide a qualitative assessment of the effect of geological factors on geotechnical properties; (3) increase the accuracy of investigations; (4) reduce costs; (5) ease comparison with previous data.

Table 1. *Comparison of Tehran alluvia based on Rieben classification (Rieben 1966)*

Factor	Alluvium			
	A	B	C	D
Age	5 Ma	700 ka	50 ka	10 ka
Lithology	Homogeneous conglomerate	Heterogeneous conglomerate	Alluvial fan	Recent alluvial
Cementation	Cemented and hard	Variable, but usually weak cement	Cementation less than A and non-hard	Non-cemented
Grain size	Clay to 100–250 mm	Very variable up to several metres	Clay to 100–200 mm	Clay to several metres
Dip layer (deg)	0–90	0–15	0	0
Thickness (m)	Maximum 1200	Maximum 60 (thickness decreases toward south)	Maximum 60	<10
Sedimentary environment	Fluvial	Fluvioglacial and periglacial	Fluvial	Fluvial
Other name (local name)	Hezardareh alluvial formation	North Tehran heterogeneous alluvial formation	Tehran alluvial formation	Recent alluvial
Location of observation in Tehran	North area	North area	North and central area	Recent and old riverbed

Geological factors affecting the geotechnical specification of Tehran alluvia

For this study a large number of pits, trenches and outcrops were visited by the authors. In addition, the data of previous investigations were used to address geological factors that affect the geotechnical properties of Tehran alluvia.

(1) Grain size and grain shape. These reflect material composition, grain formation and release from the mineral matrix, transportation, and deposition environments. Mechanical and chemical processes determine the grain shape once it is released from the matrix. Particle shape is characterized by three dimensionless ratios (Barrett 1980) identified as: sphericity S (compared with eccentricity of platiness); roundness R (compared with angularity) and smoothness (compared with roughness). An increase in particle irregularity (angularity and/or eccentricity) results in a decrease in stiffness and an increase in friction angle (Dodds 2003). The grain shapes of Tehran alluvia can be classified as round, semiround and angular according to the classification of Powers (1953). Grain sizes are variable from clay to boulders.

(2) Sedimentary age. During hundreds of thousands of years, a structure is created in coarse-grained soil. Factors that influence structure creation are hydroxide, carbonate and organic material sedimentation, grain welding caused by high pressure, and mineral recrystallization (Leroueil & Vaughan 1990). For illustration, it has been reported that the shear behaviour of natural sands is defined not only by the type of material constituents but also by the processes experienced in the ground during its geological history (Cuccovillo & Coop 1999). With the creation of a structure, the strength of soils is increased. This phenomenon can be observed in the 5 Ma Tehran alluvia. Hence, the strength of Tehran alluvium increases with age.

(3) Cementation. This is an important factor in the creation of cohesion in coarse-grained soils. Other factors that create cohesion are grain interlocking, overgrowth and welding (Barton 1993). Cementation is the most important factor to create cohesion in Tehran alluvia (Asghari 2002). The degree of cementation depends on the alluvium fabric, grain shape, age, ground water level, tectonic conditions, depth and weathering. The cementation of Tehran alluvium is secondary and created by carbonate, especially calcite (Asghari 2002). Calcite crystals are components of the source rock of Tehran alluvia. Solution of calcite crystals and then recrystallization between grains created cementation. Figure 3 shows samples of calcite cementation in microscopic thin sections of A alluvium. Figure 3a shows rhombohedral calcite crystals; this thin section shows calcite crystals that are completely crystallized, but in Figure 3b the crystallization of calcite crystals is not

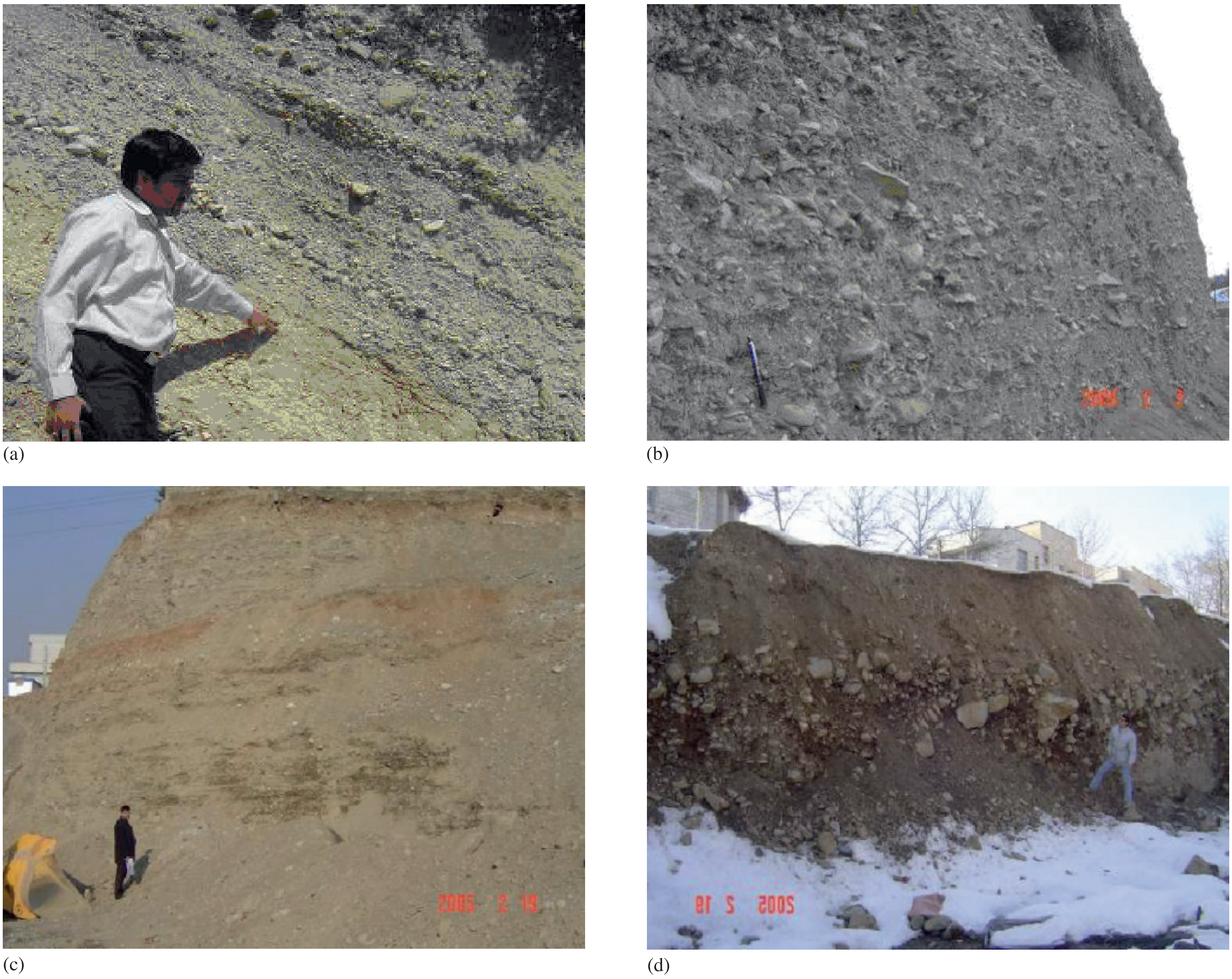


Fig. 2. Coarse-grained alluviua of Tehran. (**a**) A alluvium, showing dip and sandy interlayers. (**b**) B alluvium, showing grain-size variability and angularity. (**c**) C alluvium, showing pebble, boulder and red layers. (**d**) D alluvium, showing very large grains without cementation.

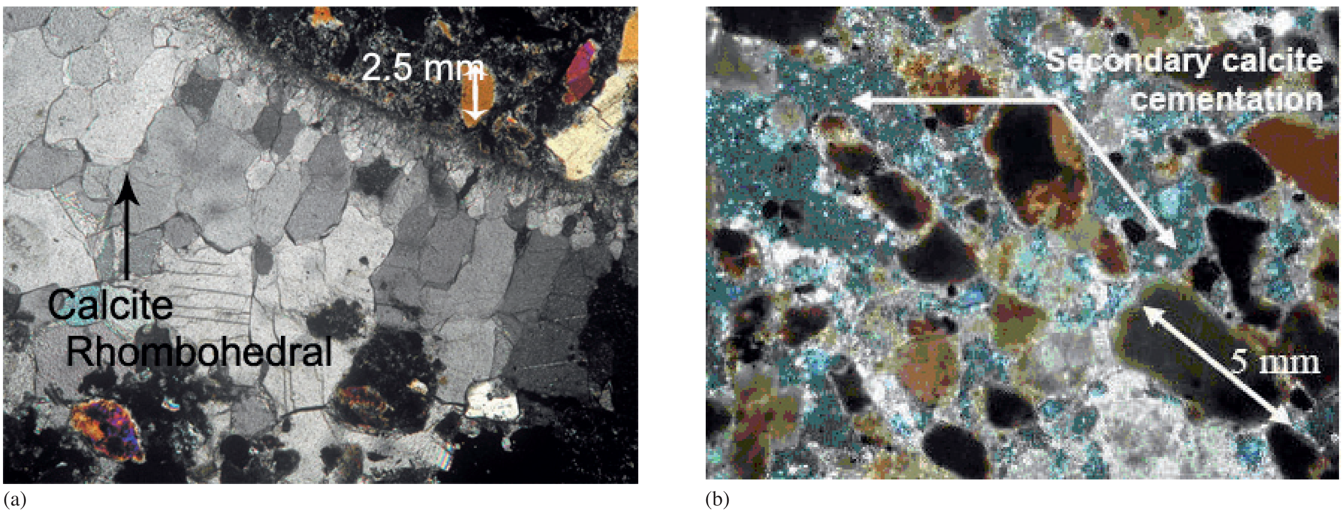


Fig. 3. Microscopic thin sections of A alluvium, showing calcite crystals: (**a**) complete crystallization to rhombohedral crystals (depth 7 m); (**b**) partial crystallization (depth 13 m).

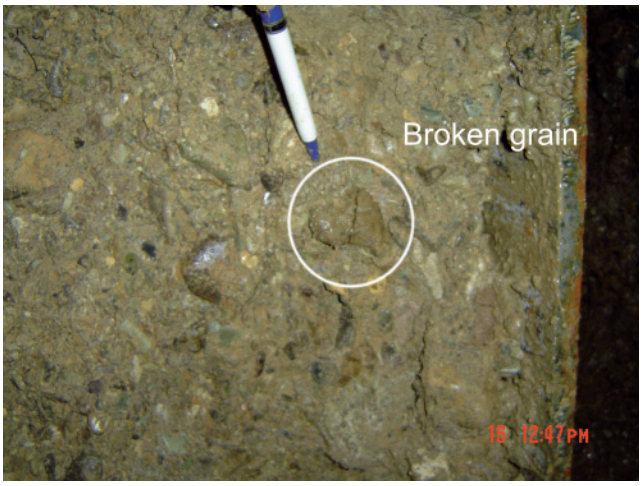


Fig. 4. Fractured grains after *in situ* direct shear test.

complete. It is clear that the strength of completely crystallized calcites is higher than that of uncompletely crystallized calcite. As shown in Figure 4, the cement between grains can be stronger than the grains themselves. Figure 4 is taken from an *in situ* direct shear test at a depth of 13 m. On the application of a shear force, some grains can be seen to have fractured before the cement material and it is apparent that the strength of the cementation material is greater than that of the intact grains. Based on observations during this study, saturation and water flow into pits can leach cement from between grains and reduce the cement-derived strength. Ismael & Mollah (1998) reached the same conclusion for naturally cemented sand. The A alluvium is the oldest alluvium of Tehran so it is the most cohesive and cemented alluvium. D alluvium is the youngest alluvium and has no cohesion. C alluvium is moderately cemented and B alluvium has weak and variable cohesion.

(d) Grain contact type. Grain contact mechanisms have been classified as point, long, interlocking and floating (Sitar 1983). In Figure 5 four kinds of contact between grains are presented. The Tehran alluvia do not have uniform grain-size distribution and usually grain shapes are angular and sometimes round. During this study it was concluded that the contact mechanisms between grains are interlocking and floating.

There are some other factors, such as faults and weathering, that affect the engineering properties of soils. Fault and fractures reduce the strength of alluvium. Water flows in faults and fractures; this could leach cement and thus reduce the strength of alluvium. Several researchers have studied the effect of weathering on the engineering properties of different types of rocks and hard soils (Cole & Sandy 1980; Lumb 1983; Kelsall *et al.* 1986; Haskins & Bell 1995). Weathering processes could also cause important changes in rock porosity (Tugrul 2004). With weathering progress, porosity increases and the strength of alluvium is reduced.

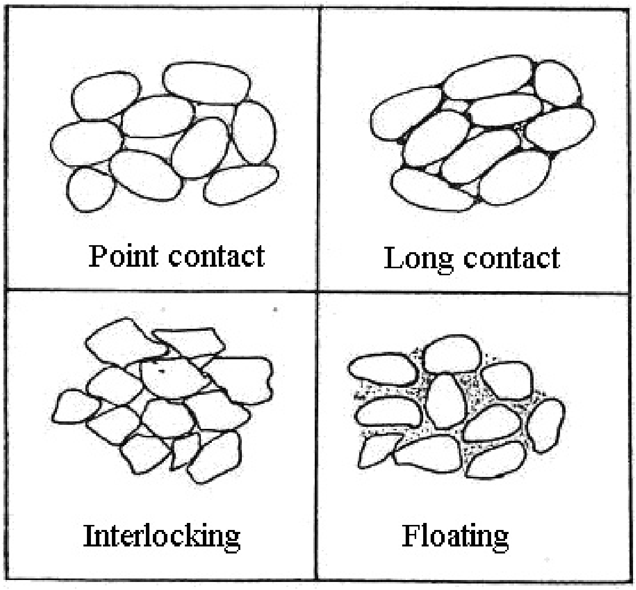


Fig. 5. Grain contact arrangements (Sitar 1983).

Weathering has more effect on young alluvium and its effect decreases with depth. In the north of Tehran there are a number of faults, which can reduce the strength of soils. The effects of weathering are more severe at faults.

To summarize, grain size and shape, sedimentary age, cementation, grain contact type, faults, fracture and weathering are major factors that influence the geotechnical properties of Tehran coarse-grained alluvia. These factors are presented in Table 2, which summarizes the visual observations on the alluvia described below.

Description of soils observed in trial pits and exposed trenches

A number of exposed trenches and excavations were visited by the authors during this study. Figure 6 shows the locations of the trial pits and excavations that were used in this study. In addition, three special pits with horizontal galleries were excavated for direct observation of the alluvia and to permit a study of grain shape, grain size, contacts, cementation and ground water, and also to carry out *in situ* tests (Fig. 6). The diameters of the pits were about 1 m with depths of 15.9, 20 and 23 m. Several observation galleries were excavated horizontally. The cross-section of galleries was triangular (height 1.8 m and base width 1.6 m). The horizontal galleries were excavated by hand tools, which are typically used by specially skilled workers. In addition, 45 trial pits excavated in previous studies were used to augment the research findings.

The visual observations of the authors are summarized in Table 2. In addition to Table 2, the following observations are of interest.

(1) In pit 1, D alluvium was observed to a depth of 7 m, below which A alluvium was encountered. Figure 7

Table 2. *Major geological factors that affect the geotechnical properties of Tehran alluvia*

Comparative factor	Alluvium			
	A	B	C	D
Grain shape	Semi-round and angular	Angular	Angular and round	Usually round
Grain size	From clay to boulders up to 500 mm diameter	Very variable grain size up to boulders of several metres diameter	From clay to boulders up to 200 mm diameter	From clay to boulders up to several metres diameter
Age	5 Ma	700 ka	50 ka	10 ka
Cementation	Strongly cemented	Uncemented	Weakly to moderately cemented	Uncemented
Contact shape	Interlocking and floating	Floating	Interlocking and floating	Floating
Structural geology	Folded and dip 0–90°	Unconformability over A series dip <10°	Horizontal	Horizontal
Weathering	Weathered on ground surface	More than A	More than B	More than C

shows a typical boundary between A and D alluvium; a similar boundary was observed in pit 2 at a depth of 10 m between D alluvium and C alluvium.

(2) Although the ground water level is very low, seepage of water could be sometimes seen in some layers. For example, water seepage was observed at a depth of 15 m in pit 2 so a pump was used for drainage during observation and *in situ* tests.

(3) Sometimes a thin layer of fine soil could be seen between coarse soils. For example, in pit 3 at 6–9 m depth there was a red layer, in which the percentage of clay was greater than elsewhere. Figure 8 shows the boundary between red and other layers. It is not a typical feature of the alluvia. Figure 9 shows a typical drawing produced to present the observations made by the authors in trial pits and horizontal galleries.

In situ tests

Because of the large grain size of some of the soils studied, it was impossible to take small samples from boreholes for laboratory testing. In addition, the use of standard penetration test (SPT) or cone penetration test (CPT) was not possible. Most previous investigations on gravelly soils have focused on the testing of sands because of the problems of testing coarse-grained soils (Crova *et al*. 1993; Lin *et al*. 2000; Asghari 2002). The research presented here was mainly based upon *in situ* tests undertaken by the authors in engineering geology surveys relating to lines 3 and 7 of the Tehran metro. In addition, *in situ* tests were carried out in three trial pits at different levels and a number of published data were used for comparison and discussion.

The *in situ* direct shear tests were undertaken based upon the procedures of BS 5930 (BSI 1999). Three frames were used, with a 600 mm width and length and 150 mm height. To prepare cubic soil samples, each frame was placed on the ground, and the soil was excavated around it so that the soil inside the frames should be undisturbed. Every test was carried out with three samples and three different constant vertical forces. The horizontal force increased continuously up to failure of the samples. The cohesion and internal friction of the undisturbed soils were determined and a total of 11 tests were carried out in five galleries. The test results showed: (1) vertical and horizontal displacements occurred immediately (about 60 s) after the vertical and horizontal forces were applied; (2) the average internal friction angles of A and C alluvia were 45 and 38° and the average cohesion of A and C alluvia were 93 and 90 kPa, respectively.

Plate load tests are commonly recognized as a reliable source for the evaluation of allowable pressure under foundations (Reznik 1995). The plate load tests were performed based on ASTM D 1194-94 (ASTM 2000). A circular plate with 300 mm diameter was used in the

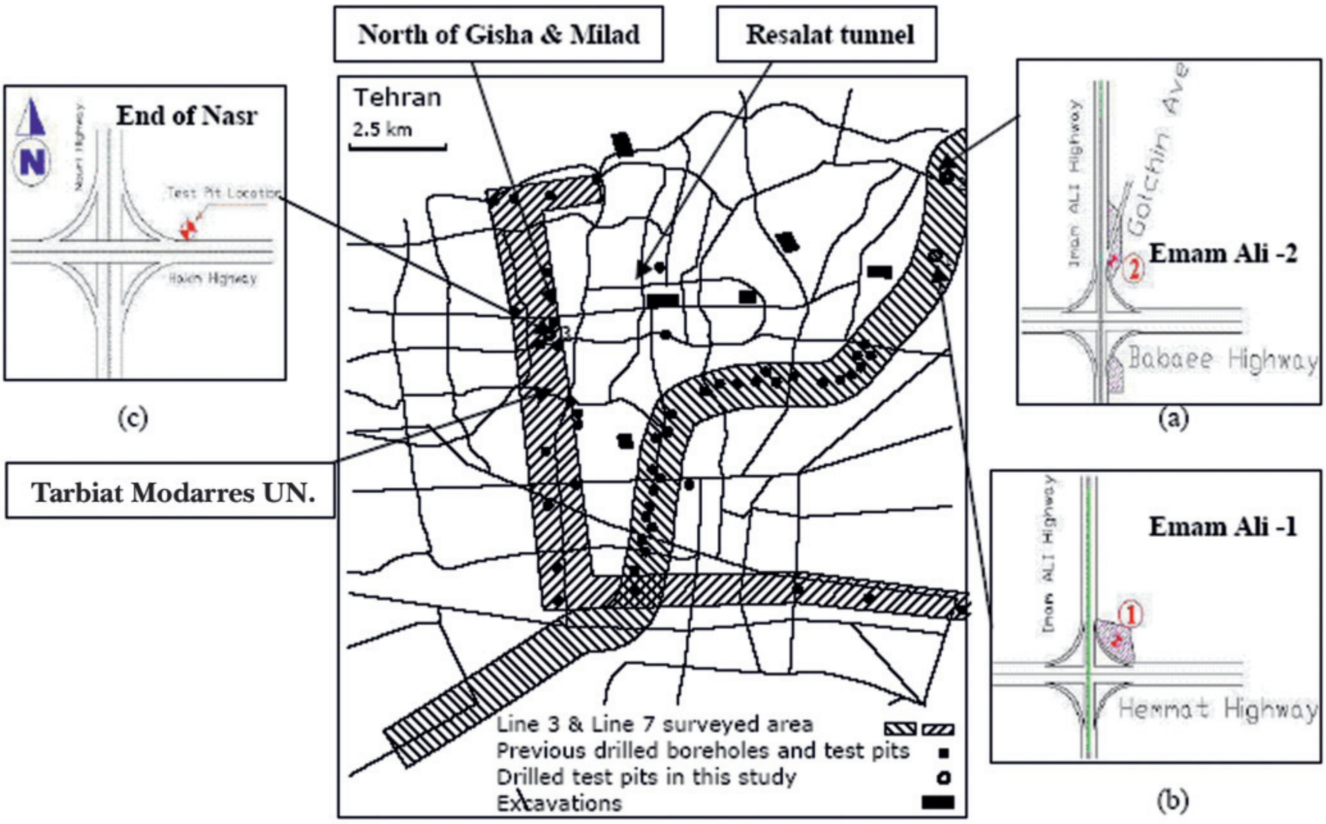


Fig. 6. Location of trial pits and metro lines 3 and 7.

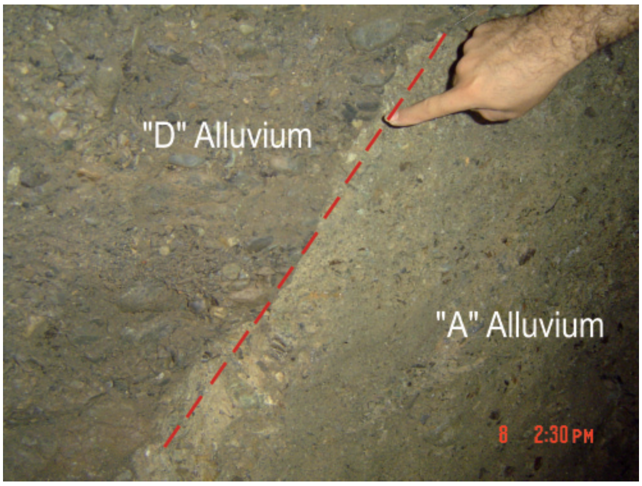


Fig. 7. Junction between A and D alluvium in pit 1.

Fig. 8. Contact between red and other layers in A alluvium in pit 3.

tests. The deformation modulus (E), modulus of subgrade reaction (K_s) and reloading modulus (K_r) were determined based on these test results. A total of 11 plate load tests were undertaken in five galleries on A and C alluvia. The test results show the following.

(a) In A alluvium following the application of a vertical force, the change of vertical settlement with time was very fast and no long-term settlement could be expected. In the case of C alluvium the soil behaviour was affected by the coarse and fine grains together and there could be long-term settlement.

(b) In one test, failure occurred around the plate once a load of 6.3 MPa had been applied. This shows that the soil could support a load of up to 6.3 MPa vertical stress under a plate.

(c) In seven tests undertaken on the A alluvium and four tests on the C alluvium, the elastic deformation modulus (E) for A and C alluvia were shown to be 164.3 and 45.9 MPa, respectively.

To determine deformation parameters at small strain, down-hole tests were conducted in three trial pits

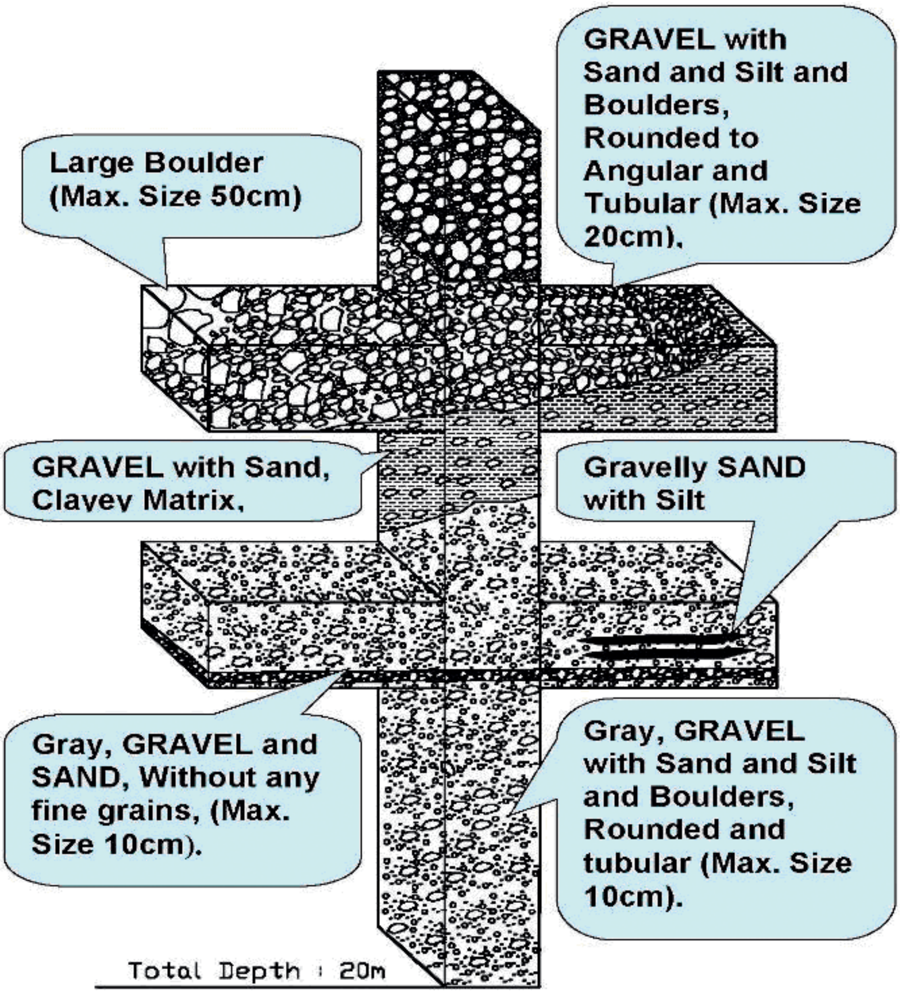


Fig. 9. Material observed in pit 3, excavated in A alluvia.

according to ASTM WK 7042 (ASTM 2005) using a '24-channel seismograph'. To find a low-cost soil investigation test, the Swedish Weight Sounding test was tried in Tehran alluvium. This procedure was first introduced in Sweden in 1917, and has been used for field surveys on subsurface profiles under railway tracks (De Ruiter 1988). The effects of overburden stress, relative density and grain composition on test results have been examined by Tsukamoto *et al*. (2004). Empirical correlation tables, proposed in Euro Code 7 (BSI 2000) were used to determine the internal friction angle and deformation modulus.

Comparison

The *in situ* test results of the present study and earlier research are compared in Table 3. This table shows that the engineering properties of A and C alluvia are different and are related to different grain sizes, cementation, and percentage of fine grains. To extend these results to other sites, more tests are required. The locations of previous studies are shown in Figure 6, which shows the engineering properties of Tehran alluvia in some areas. The values for cohesion, angle of friction and deformation modulus presented in Table 3 are based on the results of the *in situ* direct shear tests and plate load tests.

In the A and C alluvia the average ratio of $E_{\text{down hole}}/E_{\text{plate load}}$ was found to be 14 and 25, respectively. Differences between deformation modulus derived from down hole and plate loading are due to the different range of strains applied in the two tests.

In the A and C alluvia the friction angles determined by *in situ* direct shear test are about 5–10° greater than Swedish Weight Sounding test results. The differences between the internal friction angle and deformation modulus derived from the Swedish Weight Sounding and direct shear tests suggest that the empirical relationship presented in Euro Code 7 to derive internal friction angle from the Swedish Weight Sounding test should be modified for Tehran alluvia.

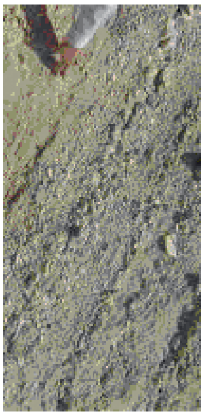
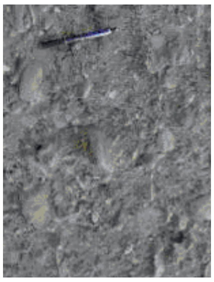
Comparison of the results suggests that there is usually agreement between the different tests. However, the

Table 3. *Comparison of in situ material test results of Tehran alluvia*

Specification	Source												
	Present study			Asghari (2002)			Pahlavan (2003), Pahlavan *et al.* (2004);			SES (1997)		Amini (1995)	
Location	Emam Ali street-2	Emam Ali street-1	End of Nasr	Resalat tunnel	North of Gisha	End of Nasr	Tarbiat Modarres Univ.	End of Nasr	North of Gisha	Milad	North of Gisha	Overall	
Alluvium	C	A	A	A	A	A	C	A	A	A	A	C	A
Classification (USCS)	GC, GP, GM, GW–GM, GC–GM, SC	GW–GM, GP–GC, GP–GM, GM–GC	GW–GM, GP–GC, GP–GM, GM–GC	GW–GM, GC, SW–SM, SC	GW–GM, GP–GC, GP–GM, GM–GC	GW–GM, GW–GP, GM–GP, GC–GM, GC	GW, GW–GC, GW–M, SW–SC, GW–GM, GW	GW, GP–GC	GW–GM, GP–GM, GC–GW, GC–GP, GC	GW–GM, GP–GM, GW–GC, SC–SM	GC, GP, GM, GW–GM, GC–GM, SC	GW, GP, GC, GP, GP–GC, GP–GM, GP–GC	GW, GP, GC, GM–GC, GW–GM, GP–GW
N_{spt}								>50	>50	>50	>50	–	–
C (kPa)	55	48	72	40						293	0	20	3
	150	57	160	87								35	15
φ (deg)	33	45	40	33						37	41	27	38
	47	52	45	37.6						41		38	42
γ_d (kN m^{-3})												17	19
												21	22
γ (kN m^{-3})	19	19	20	16.5–20.5			20	21.7	22	20	20		
	21	21	20.8										
W (%)				13–18	3–18			5–10	7–8			12–21	3–9
E (mPa)	39.2	166.1	141.2	49	111	195	36.2	154.2	167.8	125	125	15	17
	67.1	217	165.1	92	238	204	62	287.9	287.9			150	
K_s (mN m^{-3})	160	800	650	225	510	900	170	770	770		170	25	280
	260	1000	760	425	1100	940	290	1330	1330		350	250	
K_r (mN m^{-3})	1100	6000	3370	1200	2500	6000	1000	4000	860				
	2300	8600	4580	18200	11500		2000	8000	8000				
V_s (m s^{-1})	450	690	576				650	962	816				
υ	0.28	0.31	0.29		0.28			0.28		0.38	0.35		
G_s					2.57 for gravel								
G_s					2.59 for sand								
G_s					2.68 for fine grain								

N_{spt}, standard penetration number; C, cohesion; φ, angle of internal friction; γ_d, γ, dry and natural density; W, water content; E, deformation modulus; K_s, modulus of sub-grade reaction; K_r, reloading modulus; V_s, shear-wave velocity; υ, Poisson's ratio; G_s, specific gravity.

Table 4. *Determination of geotechnical properties based on geological features*

Alluvium		Geological features						Approximate values of engineering properties			
		Grain shape	Contact shape	Cement	Grain size		Elevation (m)	C (kPa)	φ (deg)	E (MPa)	Vs (m/sec)
A		Angular	Interlocking	Strongly cemented	A mixture of grain size (0–500 mm)	Low to moderate heterogeneity	1500	140–150	45–50	200–250	600–900
			Floating					60–70	35–40	100–150	
		Semi round	Interlocking					70–80	40–45	150–200	
			Floating					30–40	30–35	40–50	
B		Angular	Floating	Uncemented	0–1.5 m	Moderate to high heterogeneity	1500	No data	No data	No data	No data
					Intermediate		1300–1500	No data	No data	No data	
					Clay & Silt		1000–1100	15–20	15–20	20–30	
C		Angular	Interlocking	Weakly to moderately cemented	A mixture of grain size (0–200 mm)	Low heterogeneity	1100–1500	100–150	35–40	50–60	450–650
			Floating					20–30	35–30	30–40	
		Round	Interlocking					40–50	30–35	40–50	
			Floating					10–20	20–25	20–30	
D		Round	Floating	Uncemented	0–1.5 m	High heterogeneity	1500	No data	No data	No data	No data
					Intermediate		1500–1100	No data	No data	No data	
					Clay & Silt		1000–1100	10–40	>10	10–25	

depth of the test, water content and location of the test can cause some differences. The geotechnical parameters proposed by other researchers are for maximum depths of 4 m, because of the difficulties in performing such tests. In the current study, tests at depths greater than 4 m were successfully undertaken.

New classification and discussion

A geological classification of Tehran alluvia was first proposed by Rieben (1966) but this system does not consider the engineering properties. However, Rieben's classification has a long history of usage by local geologists and engineers. Therefore, it could be more acceptable to add engineering properties to Rieben's classification to provide a primary assessment of engineering properties of soils in civil engineering projects. Geological factors that affect engineering properties have been widely addressed in the literature and are briefly mentioned in this paper. The observations and also direct studies of the authors of the geological factors which relate specifically to the Tehran alluvia are summarized in Table 2. The results of *in situ* measurements of engineering properties of A and C alluvia can be combined, as shown in Table 4, which was produced by combining Tables 2 and 3. The results are shown in three major columns. In the first major column, the properties of Tehran alluvia based on Rieben's classification are presented, together with photographs. In the second major column, geological features (including grain shape, contact shape, cementation and grain size) that influence geotechnical properties are presented. In addition, the elevations above sea level for outcrops of these alluvia are presented. Based on the information in this column, fine-grained alluvia are seen to occur at low elevations and coarse-grained alluvia at high elevations. In the third major column, the geotechnical parameters for distinct geological features are presented. The cohesions and angles of friction presented in Table 4 are based on results of *in situ* direct shear tests, and the deformation modulus, which is for large strain, is based on results of plate load tests.

Table 4 could be considered as a framework for the quick assessment of engineering properties of alluvia using the following procedure.

Step 1: determine the type of alluvium according to Rieben's classification from Table 1 and then refer to Table 4.

Step 2: determine grain and contact shape based upon visual inspection.

Step 3: confirm the type of cement specified for the desired alluvium in Table 4.

Step 4: based upon grain size and elevation of the alluvium, select the range of engineering properties for the desired soil in Table 4.

The effect of water and faults should be considered by engineering judgement to reduce the value of engineering properties.

Table 4 could be used to determine geotechnical properties for A and C alluvia but there are not enough data available to include B and D alluvia in the system. In most cases B and D alluvia have very coarse and fine particles. Geotechnical investigations of fine-grained particles are possible by conventional geotechnical investigation methods, but investigation of coarse-grained soils is difficult because of the very coarse-grained non-cemented structure and heterogeneous nature. In this case it is possible to determine engineering properties based upon the monitoring of new constructions. These soils should be the subject of further research.

Conclusion

Coarse soils are challenging materials in ground investigations because undisturbed sampling and most *in situ* tests are inapplicable. It is also very expensive to take large samples or to undertake large *in situ* tests for small to medium-sized construction projects. Combining available geotechnical data and geological factors that affect engineering properties could produce a framework for the quick engineering assessment of any geological formation.

A new engineering–geological classification has been presented for Tehran alluvia. Most cities and areas that are located at the foot of mountains ranges could have similar geological formations and the alluvia could be similarly classified. An approach similar to that presented here could be used to add engineering properties to the geological classification of alluvia formed at the foot of mountain ranges.

The alluvia of Tehran are heterogeneous and strongly cemented; cementation between grains is usually calcite. Water flow leaches cement between grains and reduces cohesion. In the case of both A and C alluvia, contacts between grains are usually interlocking and some times floating. Heterogeneity of C alluvium is less than that of A alluvium. The percentage of fine grains in C alluvium is greater than that in A alluvium. In C alluvium, the cementitious materials are calcite and clay.

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