The ultimate shear behavior of loose gravelly sandy soils

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Abstract: During earthquakes, the shaking of the ground may cause saturated granular soils to lose their resistance and behave like a liquid. This phenomenon is called soil liquefaction and will cause settlement or tipping of buildings, failures of earth dams, earth structures and slopes.

The strength characteristics of undrained sand and silty sand have been frequently studied in recent years (Zlatovic and Ishihara 1995, Lade and Yamamuro 1997, Thevanayagam et.al 1997, Yamamuro and Lade 1998, Naeini 2001, Naeini and Baziar, 2004). However, observation of actual cases of liquefaction and flow slides which took place within loose gravelly soil material during recent earthquakes (Kokusho and Tanaka 1994, Andrus 1994 Rashidian 1995) has attracted much attention to study these materials further. However, the strength characteristics of loose gravelly sand soils under undrained loading have not been studied in depth.

In the present study, several series of undrained triaxial compression tests under monotonic loading condition were conducted on reconstituted saturated gravelly sand specimens with different gravel content ranging from 0% to 50%. The specimens were prepared at the loosest state using a wet tamping method of preparation and were sheared at different initial confining pressures. The effects of the gravel content on ultimate shear behaviour of gravelly sand soils are discussed. It was observed that the ultimate strength is sensitive to the gravel content and as the gravel content increases, the ultimate strengths decreased. However, the ultimate strength of gravelly sand is less than that of clean sand.

Résumé: Pendant les tremblements de terre, la secousse du sol peut causer des sols granuleux saturés pour perdre leur résistance et comportent comme un liquide. Ce phénomène est appelé de la liquéfaction de sol et causera le règlement ou renverser de bâtiments, les échecs de barrages de terre, les structures de terre et les pentes. Les caractéristiques de déformation de undrained sable de sable et silty a été fréquemment étudié dans les années récentes (Zlatovic et Ishihara 1995, Charger et Yamamuro 1997, Thevanayagam et.al 1997, Yamamuro et Charge 1998, Naeini 2001, Naeini et Baziar, 2004). Cependant, l'observation de véritables cas de chutes de liquéfaction et flux qui a eu lieu dans détaché gravement le matériel de sol pendant les tremblements de terre récents (Kokusho et Tanaka 1994, Andrus 1994 Rashidian 1995) a attiré la beaucoup d'attention pour étudier ces matériels plus. Mais, les caractéristiques de déformation de détaché gravement sols de sable sous undrained le chargement n'a pas été étudié en profondeur. Dans l'étude présente, plusieurs feuilleton de tests de compression undrained triaxiaux sous la condition de chargement de monotonic a été dirigé sur reconstitué saturé gravement les spécimens de sable avec étendre de contenu de gravier différent forment 0% à 30%. Les spécimens ont été préparés à l'état le plus détaché utilisant bourrer la méthode mouillée de préparation et ont été tondu de l'initiale différente limite de la pression. Les effets du contenu de gravier sur le comportement de cisailles résiduel de gravement sols de sable sont discutés. Il a été observé que la force résiduelle est sensible au contenu de gravier et comme le contenu de gravier augmente les forces résiduelles diminuées. Cependant, la force résiduelle de gravement sable est moins que le sable propre.

Keywords: liquefaction, gravel, shear strength, triaxial tests, confining pressure

INTRODUCTION

The damaging earthquakes of 1964 in Niigata, Japan and in Alaska focused geotechnical engineers' attention on liquefaction as a major problem caused by earthquake shaking. Since then, liquefaction-induced ground failures have been observed in every significant earthquake around the word. Observations from recent earthquake case histories indicate that natural soils and man made fills that contain a mix of sand and fine-grains are often susceptible to liquefaction. Many ensuing studies have concentrated on clean sand and sands with relatively insignificant amount of fines. As information accumulates, it becomes clear that soil liquefaction failures also occur in saturated granular soils.

The present study is an attempt to examine the behaviour of loose gravelly sand soils under undrained triaxial compression tests. A series of undrained monotonic tests were conducted on gravelly soil specimens prepared at the loosest state with gravel contents varying from 0% to 50%. The strength characteristics and the effect of gravel content on undrained behaviour of gravelly soils are discussed in the light of experimental results.

TESTED MATERIALS

Ardebil sand and an artificial gravel material were used in this study. In order to examine the effect of gravel content, Ardebil sand was mixed with different percentages of the gravel material. It should be mentioned that in the present study the particles with grain size more than 1 mm were assumed to be gravel material. The maximum and minimum void ratios for Ardebil sand were determined based on the Japanese Society of Soil Mechanics and Foundation Engineering method. In the case of gravelly soils the proposed method by CRIEPI was used (Kokusho, 1994). Physical characteristics of tested materials and grain size distribution curves are shown in Table 1 and Figure 1 respectively.

Table 1. Physical characteristics of tested materials

Material	Gravel[+] Content (%)	Specific Gravity G_S	Mean Grain Size D_{50}(mm)	Minimum Void Ratio e_{mim}	Maximum Void Ratio e_{max}
Ardebil Sand	0	2.670	0.17	0.746	1.09
Gravelly Sand	10	2.675	0.21	0.678	0.915
	20	2.679	0.25	0.627	0.832
	30	2.684	0.80	0.558	0.736
	40	2.687	1.70	0.469	0.647
	50	2.689	2.20	0.392	0.570

[+] denotes material with particle size greater than 1mm

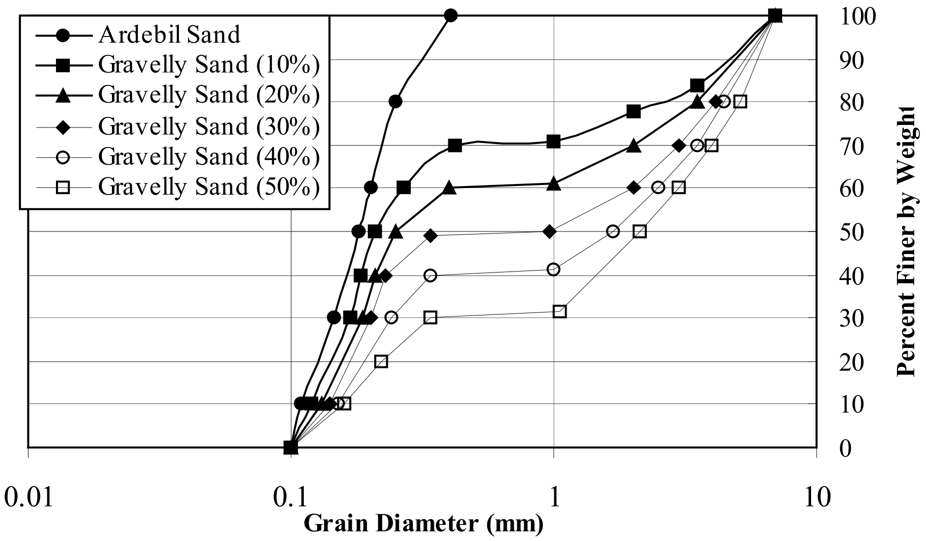

Figure 1. Grain size distribution curves of tested materials

TEST PROCEDURE

All the tests were conducted on specimens prepared by the wet tamping method in the loosest state. All specimens were 8 cm in diameter and 16 cm in height. The saturation process was performed by purging the specimen with carbon dioxide before adding water. A value of B greater than 0.97 was typically obtained at a back pressure of 200 kPa. The specimens were consolidated isotropically at mean effective pressure between 100 and 300 kPa and then sheared in undrained conditions with a constant strain rate of 1% per minute.

The surface of the specimens was smoothed to avoid membrane penetration effects by the following method: The reconstituted specimen prepared by the wet tamping method was first frozen under -20°C. After that, a thin rubber membrane of 0.3 mm in thickness, covering the specimen was removed. Since the thin membrane had been already sunk into the peripheral voids due to the applied vacuum, these voids could be easily recognized. Then, the visible peripheral voids on the surface of specimen were carefully treated manually by wet Ardebil sand. The wet Ardebil sand easily stuck to the surface of specimen because of the freezing temperature of the specimen. The final surface of specimen was slowly and carefully polished by means of sand paper. Only a small amount of sand was needed to fill the peripheral voids. It should be noted that the peripheral voids are considerably less in the case of gravelly sand compared to gravel materials. In addition it was observed that gravelly sand specimens prepared by wet tamping method had a fairly smooth surface.

TEST RESULTS

Undrained triaxial compression tests were carried out on the isotropically consolidated samples of Ardebil sand and sand-gravel mixtures with gravel content between 0-50 percent at different confining pressures to investigate the ultimate shear behaviour of loose gravelly sand soils. The summary of tests results obtained in this study is presented in Table 2, where S_U is the peak strength and S_{US} is the ultimate strength.

Table 2. Summary of tested results

Test No.	Type of Material	Gravel Content (%)	σ'_{3c} =100 (kPa)		σ'_{3c}=200 (kPa)		σ'_{3c} =300 (kPa)	
			S_U (kPa)	S_{US} (kPa)	S_U (kPa)	S_{US} (kPa)	S_U (kPa)	S_{US} (kPa)
1	**Ardebil Sand**	0	52.2	35.5	94.8	75.0	153.7	115.3
2	**Gravelly Sand**	10	37.9	32.3	73.4	63.1	121.2	103.3
3		20	34.4	29.6	64.3	53.2	113.7	91.0
4		30	31.6	26.2	61.2	49.2	97.5	82.4
5		40	29.5	24.3	58.3	48.4	92.3	76.2
6		50	27.6	23.4	54.1	46.8	83.6	70.2

The effective stress paths for Ardebil sand and specimens containing 20% of gravel at confining pressure varying from 100-300 kPa are shown in Figures 2 and 3 respectively. From the present series of experimental results it can be observed that, very loose specimens of gravelly soil show contractive behaviour. Since the specimens that were consolidated to an initial confining pressure were sheared in an undrained condition this produces pore water pressure increases. As the pore pressure increases, the mean effective stress decreases. The stress-strain behaviour showed that the shear strength showed a peak at relatively small strains and thereafter it decreased to an ultimate strength.

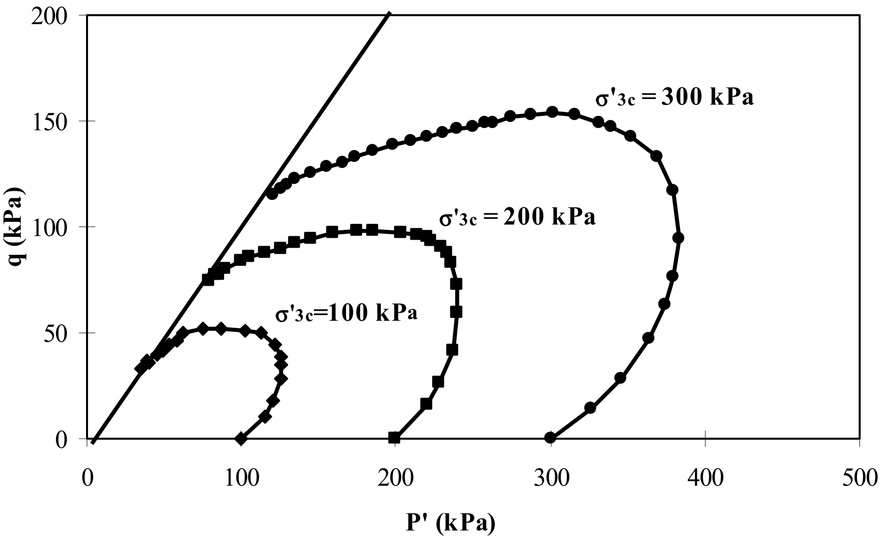

Figure 2. Stress path diagram for Ardebil sand

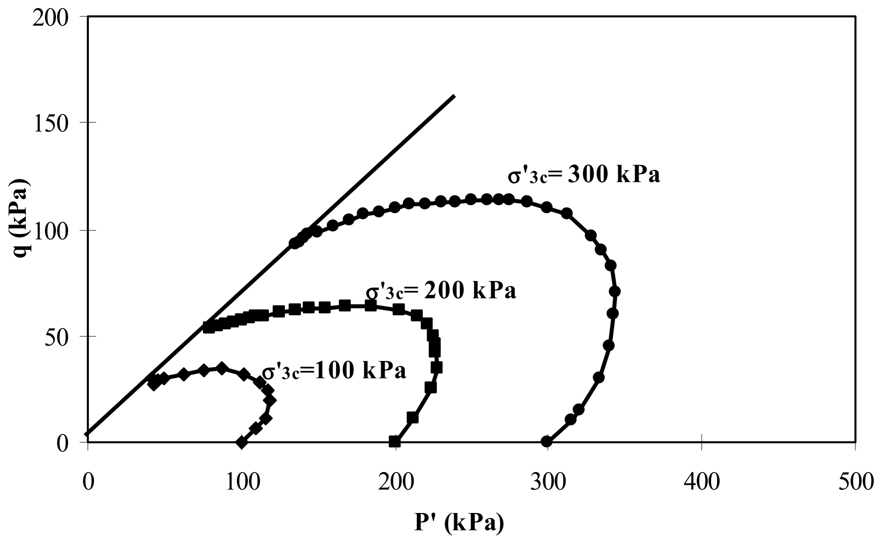

Figure 3. Stress path diagram for gravelly sand containing 20% gravel

As can be observed, for the same range of pressure used for Ardebil sand, the gravelly sand behavior also indicates a peak and ultimate strength, and the higher the initial confining pressure the higher the peak and ultimate strength, but the peak and ultimate strength of gravelly sand is less than Ardebil sand.

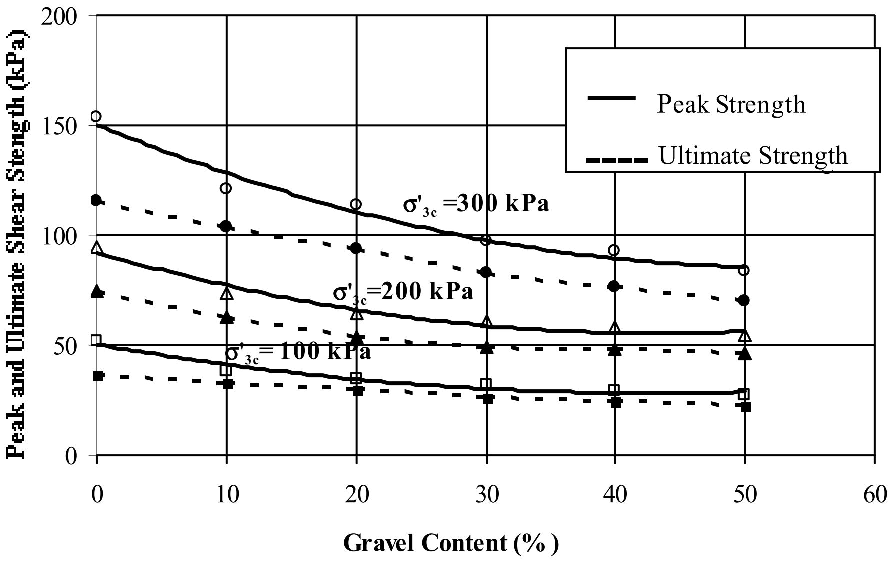

Figure 4. Peak and ultimate strength versus gravel content

Figure 4 present the peak and ultimate strength versus gravel content at 100-300 kPa confining pressure. It is clear that as the gravel content increases, the peak and ultimate strength decreases. In order to compare the behaviour of Ardebil sand with different amounts of gravel content, which causes differences in void ratio, it is very useful to compare the steady state lines of Ardebil sand and gravelly sand. Figure 5 shows the steady state lines for monotonic triaxial tests on Ardebil sand and gravelly sand. It can be seen that as the gravel content increases, the steady state line moves downwards in the log S_{us}-e diagram. This shows a decrease of ultimate strength.

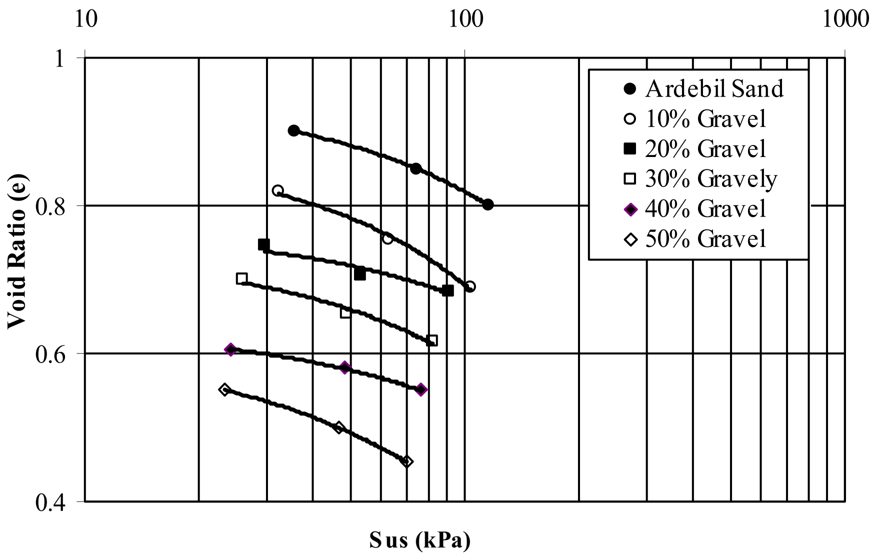

Figure 5. Steady state lines for Ardebil sand and gravelly sand

Normalized ultimate shear strength versus gravel content are presented in Figure 6. The results obtained show that the ratio of S_{us}/σ'_c is reasonably constant and independent of σ'_c. This is a very important conclusion that could allow estimating Sus in the field with no need for in-situ density measurements, if σ'_v (effective vertical overburden pressure) $=\sigma'_c$. In the current study, for the range of 0-50% gravel content in normally consolidated undrained triaxial compression tests, the following expression is suggested for the undrained shear strength which is a function of the gravel content (G.C) and effective overburden pressure.

$S_{us}/\sigma'_c = 0.356-0.0028(G.C)$ For G.C < 50%

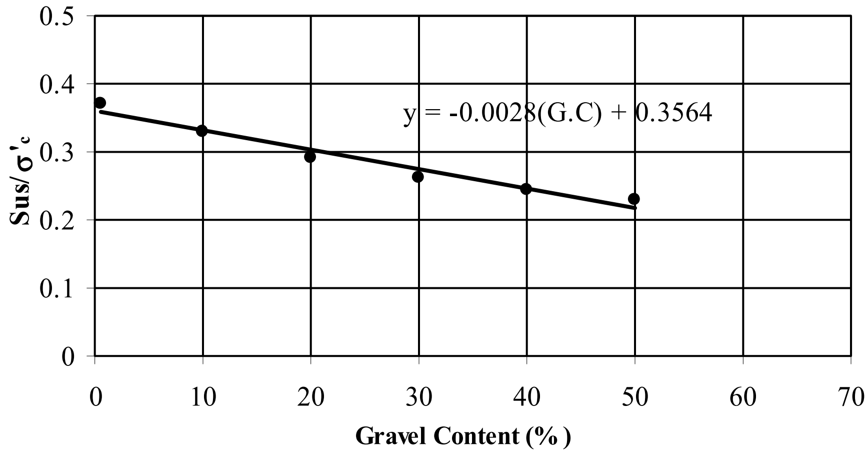

Figure 6. Normalized ultimate shear strength versus gravel content

CONCLUSIONS

Ultimate shear behaviour of loose gravelly sand soils was investigated experimentally. The effects of variation in the gravel content were studied. The following are a summary of the findings:

- From the present series of experimental results it can be observed that very loose specimens of gravelly soil show contractive behaviour.
- The peak and ultimate strength of soil are sensitive to the gravel content. As the gravel content increases up to 50%, the peak and ultimate strengths decrease. This means that the soil becomes weakened with an increase in the gravel content up to 50%.
- The position of the steady state line is influenced by the gravel content. As the gravel content increases up to 50%, the steady state line moves downward in the log S_{us}-e diagram and the contractiveness is increased.
- Normalized ultimate shear strength is reasonably constant and decreases with increasing gravel content up to 50%.

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