



# Effect of Gravel Content on the Shear Behavior of Sandy Soils

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## Abstract

Most of the previous constitutive models used for investigation of the shear behavior of sandy soils have been developed without consideration of the oversize particles. The size of experimental samples is an important limitation in this case. In this research a laboratory study has been planned to investigate the shear strength of sandy soils containing different gravel contents. The tests conducted using a large scale direct shear apparatus with a 300<sup>mm</sup>×300<sup>mm</sup> shear box. All the tests have been performed on dry samples in drained condition. The gravel contents of 20, 40 and 60 percent were used in sample preparation. The tests conducted in three different densities of 35, 60 and 85 percent and three different surcharges of 1.5, 3 and 4.5 kg/cm<sup>2</sup>. It was observed that the increase in gravel content and relative density results to an increase in the shear strength and dilation of the mixture. The gravel particles are floating in sandy soil matrix in lower gravel contents. As a result the shear behavior is mainly controlled by the sandy matrix behavior. However, as the gravel content increases in sandy soil, the non floated state of the gravel controls the behavior of sand-gravel mixture.

**Keywords:** Shear strength, sandy soil, density, Gravel content, surcharge.

## Introduction (with two 9 pt lines space from the keywords)

The shear strength of sand-gravel mixtures is an important aspect in geotechnical design. However, due to the limitations of laboratory devices, most of the tests have been performed by removing the oversize particles from the soil. Fragaszy et al. (1990, 92) introduced the concept of "far-field matrix density" to consider the effects of oversize particles on the density, static strength and deformation behavior of sand-gravel mixtures. They divided the matrix into two components that are the matrix immediately adjacent to the oversize particles, called "near-field matrix" and the material further away from the oversize particles, called "far-field matrix". They have shown that the presence of oversize particles decreases both the far-field and near-field matrix densities. Therefore the static strength of sand-gravel mixture reduces with increase in gravel content. It was determined that the static strength and deformation behavior of granular soils with oversize particles are governed by the far-field matrix density when the oversize particles are floated in a finer-grained matrix. Evans and Zhou (1995) confirmed this theory for the cyclic strength of sand-gravel mixtures. However, other researchers like Yagiz (2001), Kokusho et al. (2004) and Simoni and Houlsby (2006) concluded that the shear strength of mixture increases with gravel content. Vallejo (2001) showed that the shear strength of the mixtures is controlled by the frictional resistance of the gravel grains when its content is more than 70% in the mixture. In gravel content less than 40%, the shear strength of the mixtures is controlled by the frictional resistance of the sand grains. Finally when the gravel content is between 40 and 70%, the shear strength of the mixture is partially controlled by the frictional resistance provided by the gravel grains in the mixtures.

There are many parameters affecting the shear strength of mixtures containing oversize particles like the gravel content, relative density, surcharge and size and shape of oversize grains. In this paper, the effects of gravel content and relative density on the shear behavior of sand-gravel mixture are investigated.

## Materials Used in the Study

The Babolsar sand with high uniformity is used as the matrix material. Sand grains are sub rounded to sub angular in shape. Also the gravel grains with a maximum size of 25<sup>mm</sup> were used to prepare the sand-gravel mixtures. Figure 1 shows a picture of the materials used. Grain size distribution of sand, gravel and their mixture with 20%, 40% and 60% gravel content by weight are also shown in figure 2.

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Figure 1.a- Oversize particles

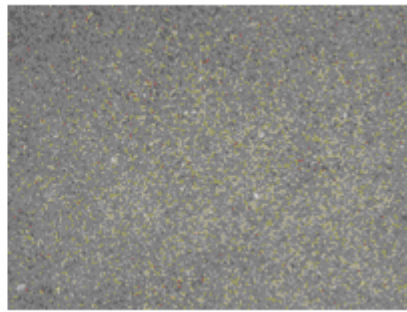


Figure 1.b- Sandy matrix

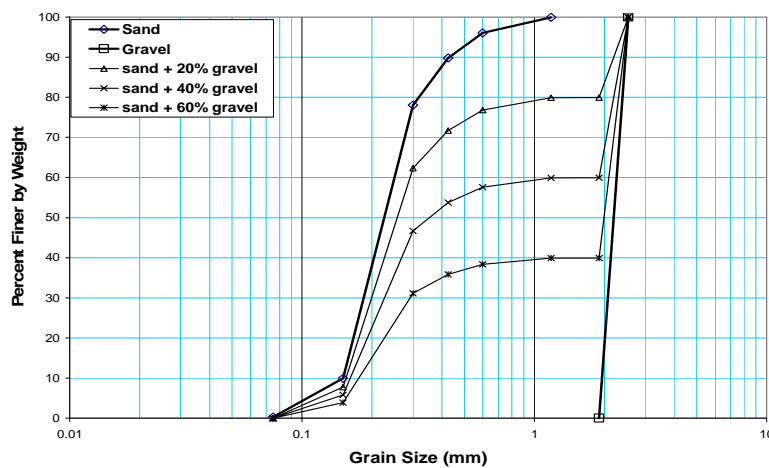


Figure 2- Grain size distributions for sand, gravel and the mixtures

The maximum and minimum void ratios for the mixtures were determined according to ASTM D-4253 and ASTM D-4254. The Results are shown in figure 3. As can be seen from figure 3, the maximum and minimum dry densities increase with gravel content up to 60%. As studied by Fragaszy et al. (1992), the gravel content less than 60% has little effect on the shear strength because it is floated in the sandy matrix.

Both the maximum and minimum dry densities decrease when the gravel content exceeds 60 percents. It may be concluded that stronger contacts between gravel particles influence the shear strength of the mixture significantly at this state.

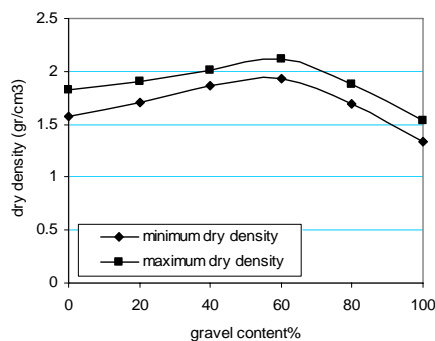


Figure 3.a- Maximum and minimum dry densities

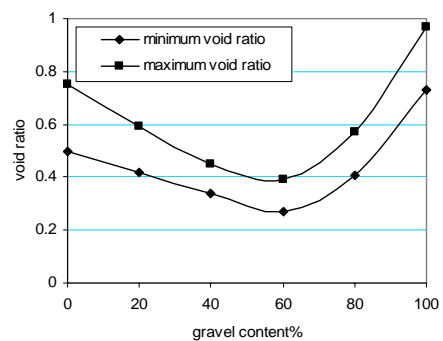


Figure 3.b- Maximum and minimum void ratio

### The Effect of Gravel Content on the Shear Strength

The variations of shear stress and the volumetric strain with shear strain for samples with 0, 20, 40 and 60% gravel content under a surcharge of 3 kg/cm<sup>2</sup> and relative density of 60% are shown in figure 4.

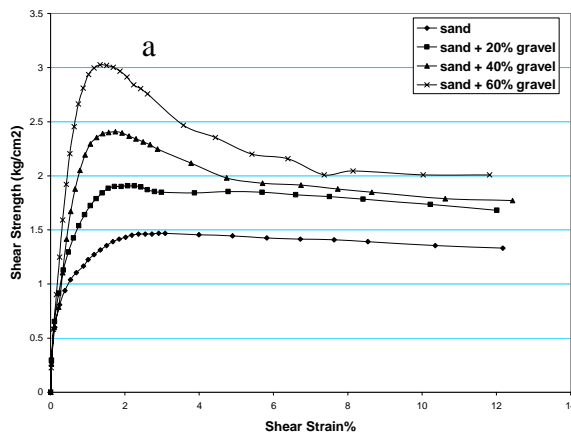


Figure 4.a- Shear stress vs. shear strain

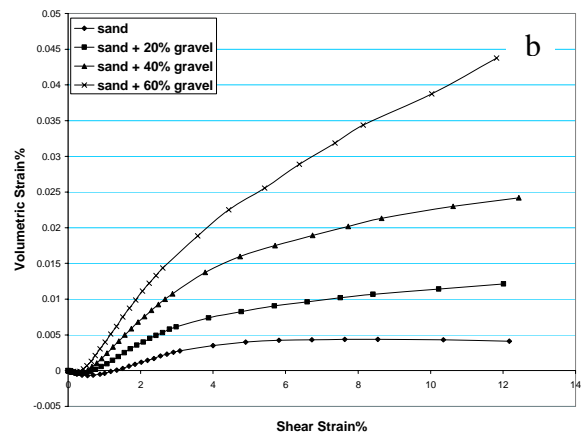


Figure 4.b- Volumetric strain vs. shear strain

It can be seen that the shear strength of the mixture increases with increase in gravel content. This is consistent with Simoni and Houlsby (2006) and Yagiz (2001) results and is against the matrix theory of Fragaszy et al. (1992). As stated by Fragaszy et al. (1992), the following relation can be used to obtain the far-field matrix density:

$$\rho_{mf} = \frac{(1-p)}{\left[ \left( \frac{1}{\rho_t} \right) - \left( \frac{p}{\alpha \cdot G_{opw}} \right) \right]} \quad (1)$$

In this equation  $p$  is the decimal fraction by mass of the oversize particles;  $\rho_t$  is the dry density of the matrix soil;  $G_{opw}$  is the mass density of the oversize particles; and  $\alpha$  is a correction factor that takes into account the added void space due to the oversized particles. Evans and Zhou (1995) used this equation for different sand-gravel mixtures and determined the values of  $\rho_{mf}$  as shown in table 1.

Table 1- Far-field matrix density evaluation (Evans and Zhou 1995)

Symbol	Soil			
	sand	sand-gravel composite		
gravel content (%)	0	20	40	60
$G_s$ , mixture	2.63	2.65	2.67	2.68
$e_{max}$ , mixture	0.98	0.8	0.62	0.51
$e_{min}$ , mixture	0.58	0.51	0.4	0.32
$D_r$ , mixture (%)	40	40	40	40
$D_r$ , matrix (%)	40	34	29	0
$\rho_{mixture}$ (Mg/m <sup>3</sup> )	1.44	1.57	1.75	1.87
$e_{mixture}$	0.82	0.68	0.53	0.44
$\alpha$	0.5	0.96	0.97	0.97
$\rho_{far-field,matrix}$	1.45	1.44	1.43	1.31
$D_r$ , far-field,matrix	40	35	32	0

The table shows that the far-field matrix density decreases from 1.45Mg/m<sup>3</sup> for sandy soil to 1.31Mg/m<sup>3</sup> for the sand mixed with 60% gravel content. As it may be observed, the far-field density decreases with increase in gravel content. This results in lower mixture shear strength in higher gravel contents (Fragaszy et al. 1992). Also the ratio of mixture shear strength normalized to the shear strength of sand is determined for different surcharges in samples with 0, 20, 40 and 60% gravel content. Figure 5 shows the significant effect of gravel content on this ratio. It can be concluded that the oversize effect on the shear strength increases with the increase in gravel content.

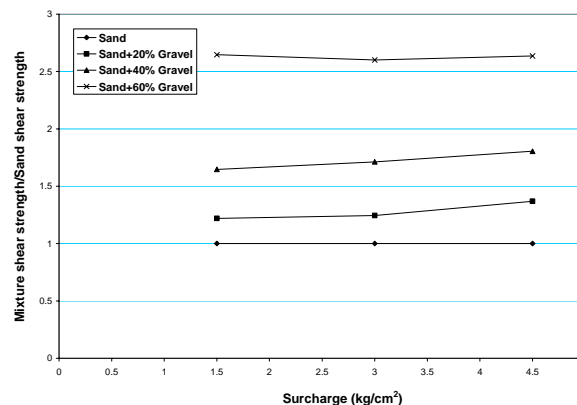


Figure 5- Effect of gravel content on the ratio of gravely sand strength to sand strength

### The Effect of Relative Density on the Shear Strength of Sand-gravel Mixture

In order to consider the effect of relative density on the shear strength, the sample are prepared at loose (35%), medium (60%) and dense (85%) relative densities. The variation of the shear stress and volumetric strain versus shear strain for samples with 20% gravel content under a surcharge of 3 kg/cm<sup>2</sup> in different densities are shown in figure 6.

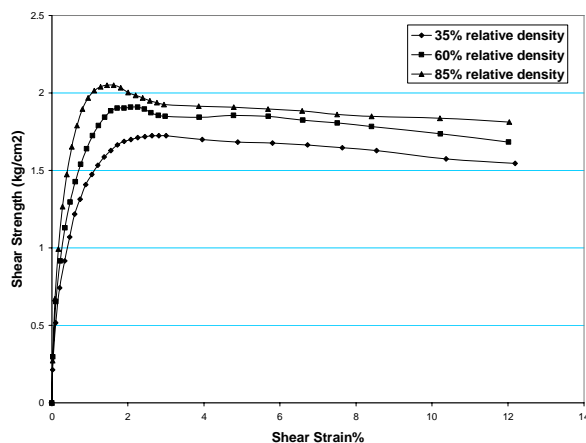


Figure 6.a- Shear stress versus shear strain

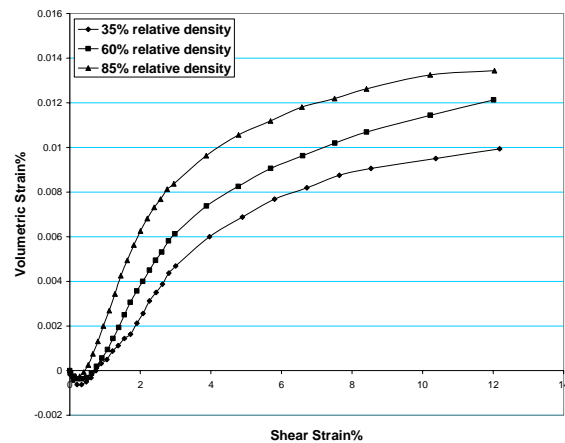


Figure 6.b- Volumetric strain versus shear strain

Figure 6 shows that the increase in relative density increases the shear strength of the mixture. Peak shear strengths of mixture at the loose, medium and dense states are 2.46, 2.67 and 2.89 kg/cm<sup>2</sup> respectively. Comparing the peak shear strength values of the mixture in different gravel contents in figure 4, it can be concluded that the rate of increase in shear strength due to the gravel content increase is more compared to the relative density.

The variation of friction angle versus relative densities in different gravel content is shown in figure 7. As indicated in this figure, the increase in gravel content has a significant effect on the friction angle. Also the gravel content effect on the friction angle is more than the relative density.

### Conclusion

According to the direct shear test results on sand-gravel mixtures in different gravel contents and relative densities, the following results could be concluded:

1. The shear strength of mixture is not controlled by the far-field matrix density introduced by Fragaszy et al. (1992). The increase in gravel content increases the shear strength and dilation of the mixture.
2. The increase in relative density increases the shear strength of the mixture. But the gravel content has a more effect on the shear strength than the relative density.
3. The friction angle of the mixture increase with both gravel content and relative density.

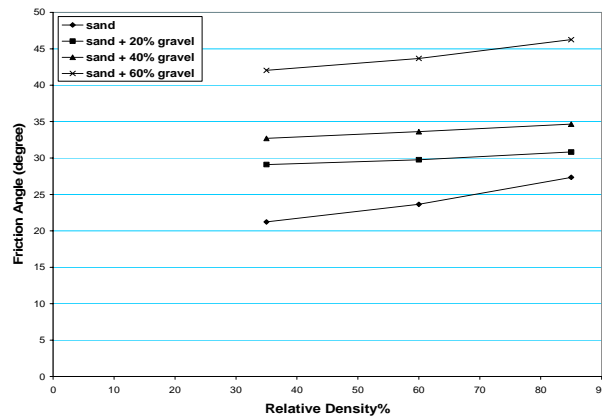


Figure 7- Effect of gravel content on friction angle

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