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# EFFECT OF PLASTIC FINES ON OVER CONSOLIDATED MINING SAND

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## ABSTRACT

In-situ Malaysian soils in tin mining areas usually occur as mixtures of sand and clay in widely varying proportions. Their engineering behaviour is different from that of clean mining sands. Natural soils are often in a structured and over consolidated state. It was found that the rate of loss of pre-consolidation history in sand is much faster than that in clay. This paper addresses the effects of plastic fines on the shear strength behaviour of over consolidated mining sands. An experimental investigation on samples of reconstituted clean mining sand containing different proportions of plastic fines was carried out. The samples were subjected to undrained triaxial compression tests under various levels of mean effective consolidation stress and unloaded to 100 kPa during shearing to achieve the OCR required. The stress-strain-pore pressure response, peak strength and soil stiffness were measured and evaluated for each plastic fines percentage in the over consolidated soil samples.

**Keywords:** mining sand, plastic fines, OCR, triaxial test, strength, stiffness, pore pressure.

## INTRODUCTION

The in-situ state in natural soils has normally undergone a complex stress history. Over consolidation is usually due to geological factors, for example, the erosion of overburden, the melting of ice sheets after glaciations and a permanent rise of the water table. Over consolidation of soils may be produced artificially by means of surface or dynamic compaction (Hanna and Saad 2001; Bentler and Labuz 2006). Over consolidation can also be due to higher stresses previously subjected to a specimen in the triaxial apparatus.

Evaluation of the stress history, or over consolidation ratio has been widely researched in the field of soil mechanics. Skempton (1964), who was among the pioneers of research related to landslide and soil mechanics, concluded that the post-softening particle arrangement of an over consolidated soil mass is still denser than a normally consolidated soil at the same normal stress. However, Skempton also concluded that residual strength is independent of stress history (OCR) and it is mainly affected by the clay fraction of the soil. Skempton (1964), Kenney (1967), Lupini *et al.* (1981), Gibo *et al.* (1987), Tika (1999) and Moore (1991) have found that the residual strength of soils depends on factors such as normal effective stress, clay mineralogy, particle shape and size distribution, pore water chemistry and rate of displacement, excluding stress history (OCR) as a contributing factor to residual strength.

Numerous investigations have been conducted to examine the effects of fines on the undrained behavior of sands. The effects of non-plastic fines on the undrained behavior of sands were studied in both cyclic and monotonic tests (Lade and Yamamuro 1997, Polito and Martin 2001 and Thevanayagam *et al*. 2002). In sands and plastic fines mixture, the parameters such as the plasticity of fines, fines content, clay mineralogy, pore water chemistry appear to influence the undrained behavior of sands (Georgiannou *et al*. 1991, Prakash and Sandoval 1992 and Gratchev *et al*. 2007).

The objective of this study is to investigate the effects of plastic fines on over consolidated mining sand and to assess the main factors affecting the mechanical behavior of these soils. The results of undrained tests performed on over consolidated mining sand and with different percentages of plastic fines ranging from 0% to 40% are presented and discussed. The specimens were consolidated under isotropic effective confining pressures, 100, 200, 400 and 600 kPa; and then unloaded to final current effective stress of 100 kPa for OCR = 1, 2, 4 and 6, respectively.

## EXPERIMENTAL PROGRAMME

### Soil constituents selected

Mining sand obtained from tin ore mining areas was used as coarser grain matrix. The finer grain matrix was composed of kaolin clay. Figure-1 shows the grain-size distributions of mining sand and kaolin clay used in this study. The mining sand used is angular and has a value of specific gravity of solid particle of 2.63. The distribution curve for mining sand has a coefficient of uniformity of 2.08 and coefficient of curvature of 1.27 and hence it is classified as well graded. Figure-2 shows the dry density and water content relationship for the mining sand. The minimum and maximum dry densities of the mining sand are 1413 kg/m$^3$ and 1565 kg/m$^3$, respectively. The kaolin clay used has a liquid limit of 61%, plastic limit of 34%, plastic index of 27%, specific gravity of 2.69, optimum moisture content of 38%, and maximum dry density of 1350 kg/m$^3$ and is classified as clay with high plasticity (CH) (BS 5930: 1999).

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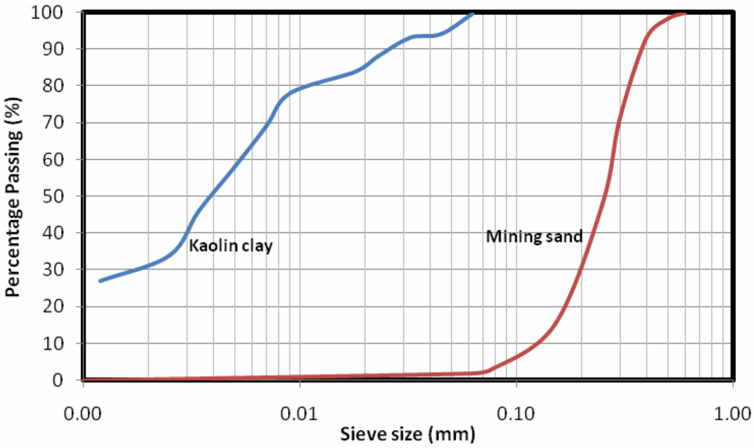


**Figure-1.** Sieve analysis for mining sand and Kaolin clay.

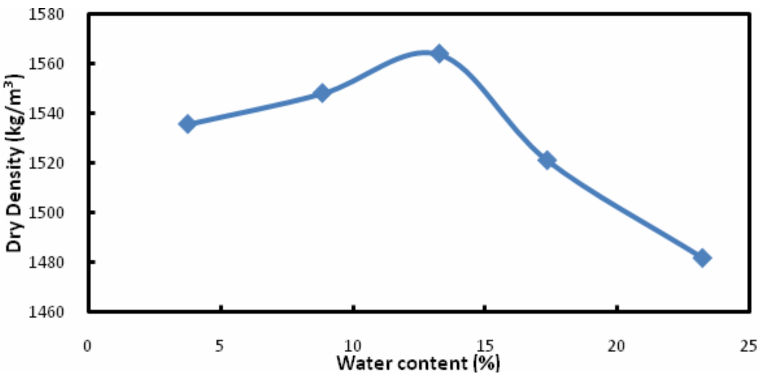


**Figure-2.** Dry density versus water content from standard proctor test on mining sand.

**Soil sample preparation**

The sand-clay soil samples were prepared on dry weight basis by mixing oven dried mining sand and kaolin clay thoroughly. The mining sand and kaolin clay were mixed manually in a dry state until the mixtures were observed to be visually homogeneous. The soil specimens in this study were 50 mm in diameter and 100 mm in height, and they were prepared with 0%, 10%, 20%, 30% and 40% plastic fines (kaolin clay). They were constructed by dry-tamping method, which was performed by compacting the prepared sand-clay mixture in five layers to a selected percentage of the required dry unit weight of the specimen. Saturation was achieved by applying cell and back pressures. Full saturation of soil samples was assumed to have taken place when Skempton's B-parameter was greater than 0.95.

**Testing procedures**

After saturation stage, the specimens were consolidated under isotropic effective confining pressures, 100, 200, 400 and 600 kPa; and then unloaded to final current effective stress of 100 kPa for OCR = 1, 2, 4 and 6, respectively. Table-1 shows the over consolidated isotropic condition of triaxial compression tests. All shear tests were conducted on the soil samples after consolidation phase. The specimens were then sheared under undrained condition (CIU) at the rate of 0.4 mm/minute up to an axial strain of 25%. The testing procedures and data acquisition were performed by using GDSLAB software and GDS Data Acquisition System as shown Figure-3.

**Figure-3.** Computer-controlled triaxial testing equipment.

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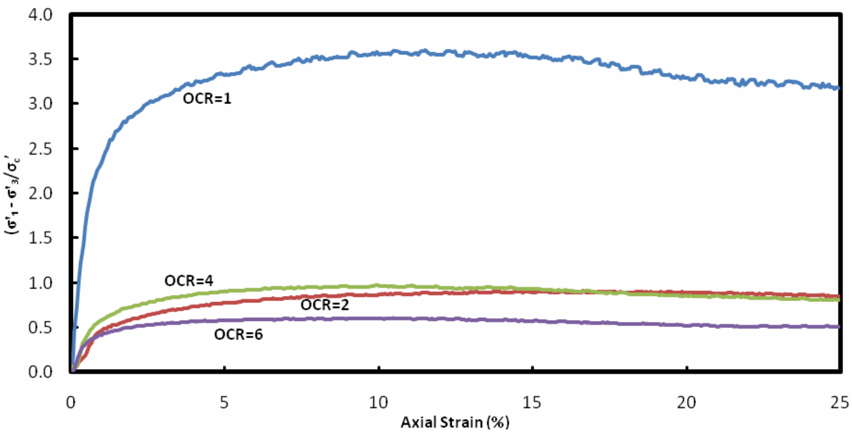
**Table-1.** Over consolidated isotropic undrained triaxial tests of mining sand-clay.

| **Kaolin clay** | **Soil sample** | **Preconsolidation pressure** (kPa) | **Current effective pressure** (kPa) | **OCR** |
|---|---|---|---|---|
| 0% | MC 001 | 100 | 100 | 1 |
| 10% | MC 101 | 100 | 100 | 1 |
| 20% | MC 201 | 100 | 100 | 1 |
| 30% | MC 301 | 100 | 100 | 1 |
| 40% | MC 401 | 100 | 100 | 1 |
| 0% | MC 002 | 200 | 100 | 2 |
| 10% | MC 102 | 200 | 100 | 2 |
| 20% | MC 202 | 200 | 100 | 2 |
| 30% | MC 302 | 200 | 100 | 2 |
| 40% | MC 402 | 200 | 100 | 2 |
| 0% | MC 003 | 400 | 100 | 4 |
| 10% | MC 103 | 400 | 100 | 4 |
| 20% | MC 203 | 400 | 100 | 4 |
| 30% | MC 303 | 400 | 100 | 4 |
| 40% | MC 403 | 400 | 100 | 4 |
| 0% | MC 004 | 600 | 100 | 6 |
| 10% | MC 104 | 600 | 100 | 6 |
| 20% | MC 204 | 600 | 100 | 6 |
| 30% | MC 304 | 600 | 100 | 6 |
| 40% | MC 404 | 600 | 100 | 6 |

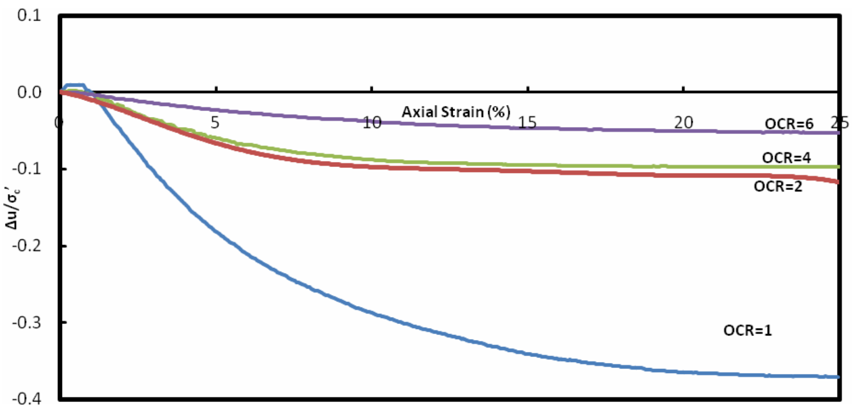
## TEST RESULTS

### (i) Clean mining sand

Figure-4 shows the normally and over consolidated undrained triaxial test (CIU) results of clean mining sand. Initially, the samples were consolidated under isotropic effective confining pressures ($\sigma_c$') 100, 200, 400 and 600 kPa and then unloaded to final current effective stress 100 kPa for OCR = 1, 2, 4 and 6, respectively. The normalised deviator stresses (($\sigma_1$'-$\sigma_3$')/$\sigma_c$') of the clean mining sand samples reached their maximum levels at low strain and exhibited strain-softening tendency before failure shown in Figure-4(a). The normalised deviator stresses for over consolidated clean mining sand are much lower than that of normally consolidated clean mining sand. The specimens initially showed contractive behaviour with increasing confining pressures under loading and then swelled under unloading with low confining pressures. The maximum strengths of clean mining sand increased with increasing of effective confining pressure. Figure-4(b) shows the relationship between the shear strain and normalised excess pore pressure ($\Delta u/\sigma_c$') for clean mining sand. The excess pore pressure of normally consolidated sample showed positive values under low strain level and exhibited eventually negative values with higher strains. The excess pore pressures of over consolidated specimens were negative in values, indicating the dilatancy between soil particles of specimens because the current confining pressure was less than the past maximum confining pressure.




(a) Normalised deviator stress-strain curves.

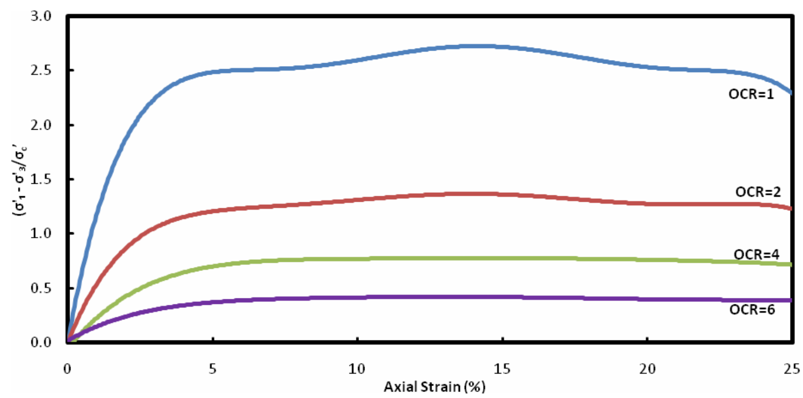



(b) Normalised excess pore pressure versus axial strain.

**Figure-4.** CIU Results for medium dense clean mining sand.

**(ii) Effect of plastic fines contents**

Figure-5 shows the results of the specimens with 10% of plastic fines content. The effect of plastic fines content on the normalized deviator stress is illustrated in Figure-5(a). The normalized deviator stress for normally consolidated mining sand with 10% of plastic fines content is lower than that for normally consolidated clean mining sand. However, the normalized deviator stresses for over consolidated mining sand with 10% plastic fines were similar to those for over consolidated clean sand. Figure-5(b) indicates that the specimens with 10% matrix fines exhibit dilatant tendency resulting negative excess pore pressure after the initial contractive behavior.




(a) Normalised deviator stress-strain curves.

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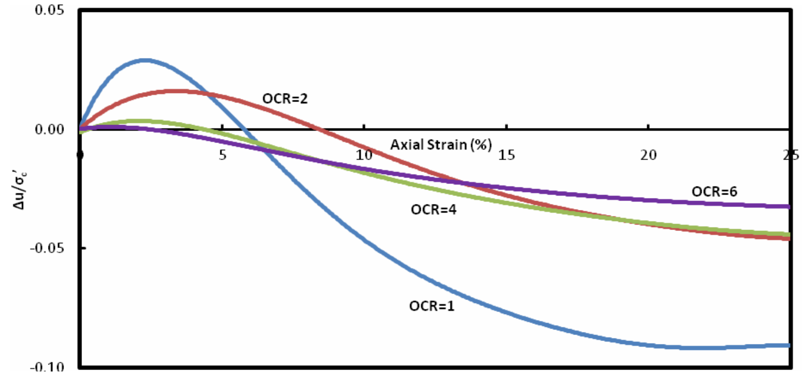
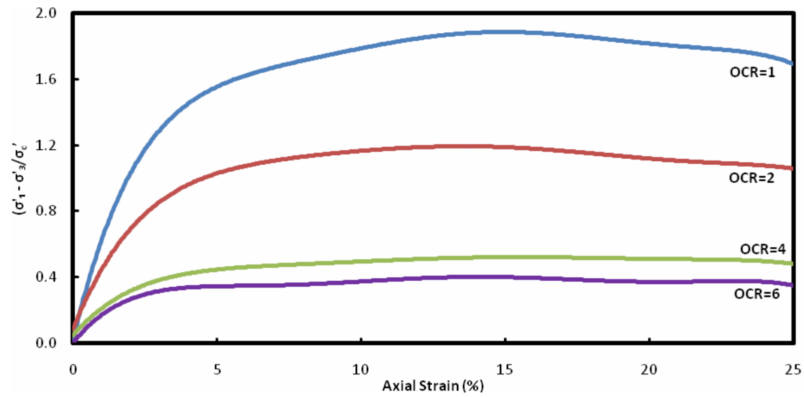


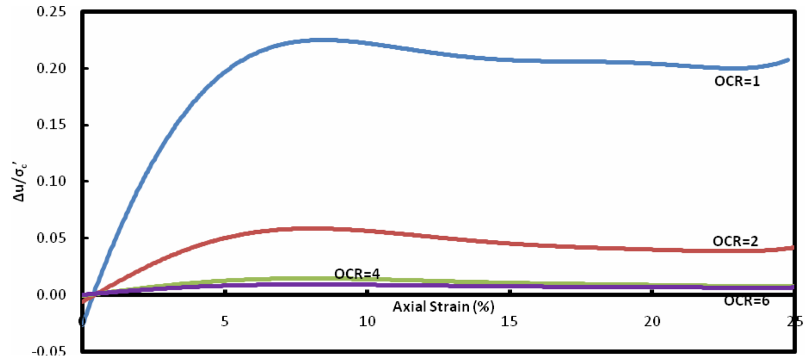

(b) Normalised excess pore pressure versus axial strain.

**Figure-5.** Stress-strain-pore pressure curves with 10% fines content.

Figures 6-8 show the results of soil specimens with 20%, 30% and 40% plastic fine contents, respectively. Generally, the normalised deviator stress decreases with increasing over consolidated ratio. The soil specimen exhibits contractive tendency resulting positive excess pore pressure with increasing plastic fines content. The maximum normalised positive excess pore pressure decreases with increasing over consolidation ratio. It appears that increasing plastic fines content is causing the soil specimens to become more contractive.




(a) Normalised deviator stress-strain curves.




(b) Normalised excess pore pressure versus axial strain.

**Figure-6.** Stress-strain-pore pressure curves with 20% fines content.

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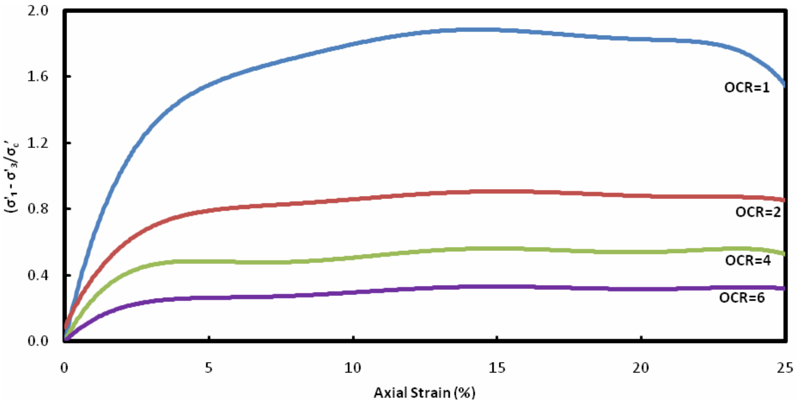
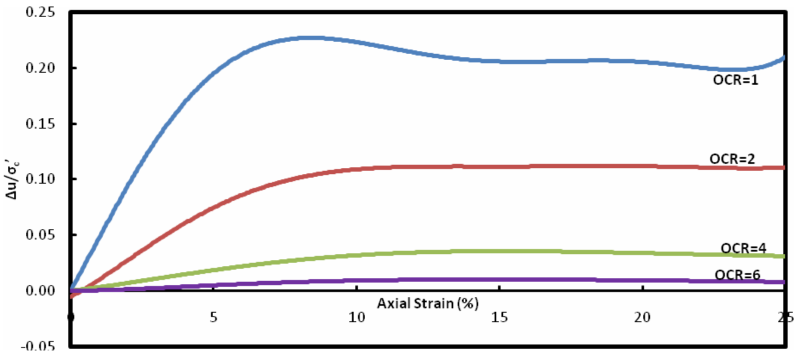
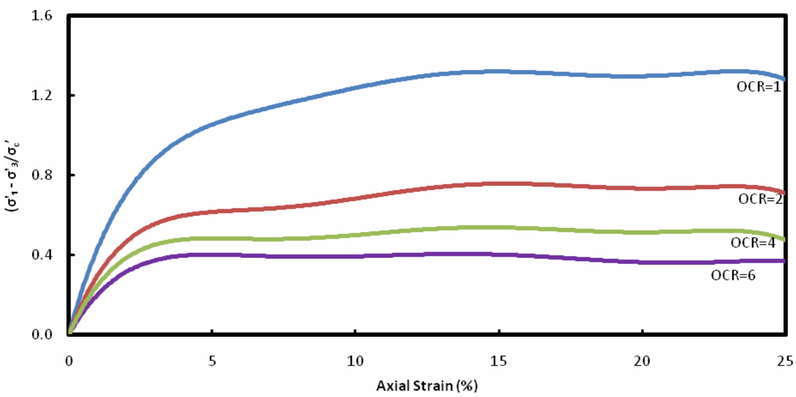



(a) Normalised deviator stress-strain curves.

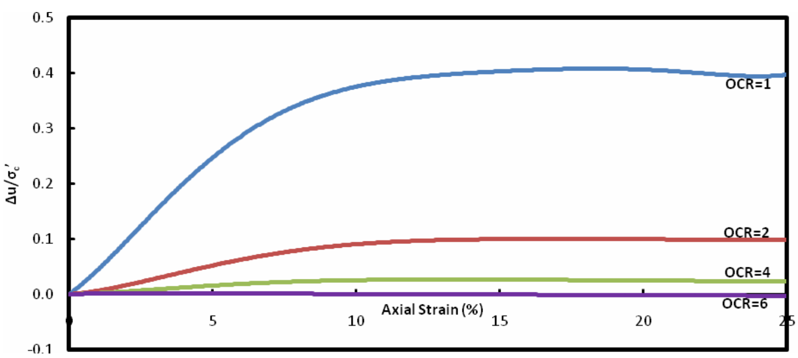



(b) Normalised excess pore pressure versus axial strain.

**Figure-7.** Stress-strain-pore pressure curves with 30% fines content.




(a) Normalised deviator stress-strain curves.




(b) Normalised excess pore pressure versus axial strain.

**Figure-8.** Stress-strain-pore pressure curves with 40% fines content.

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**(iii) Soil stiffness**

Figures 9 and 10 show the effect of OCR and plastic fines content on the initial tangent modulus ($E_i$) and secant modulus at 50% maximum deviator stress ($E_{50}$) of the mining sand respectively. The initial tangent modulus and secant modulus of mining sand increase with increasing OCR because the high confining stress causes the soil samples to be densely packed together and therefore stiffer. However, they decrease with addition of plastic fines which may be a result of more compressible clay fines entrapped between sand contacts, and therefore, deform and reshape themselves during isotropic compression and they do not have well-developed contacts with the sand particles as static stresses are not effectively transferred through the fines (Carraro *et al*. 2009).

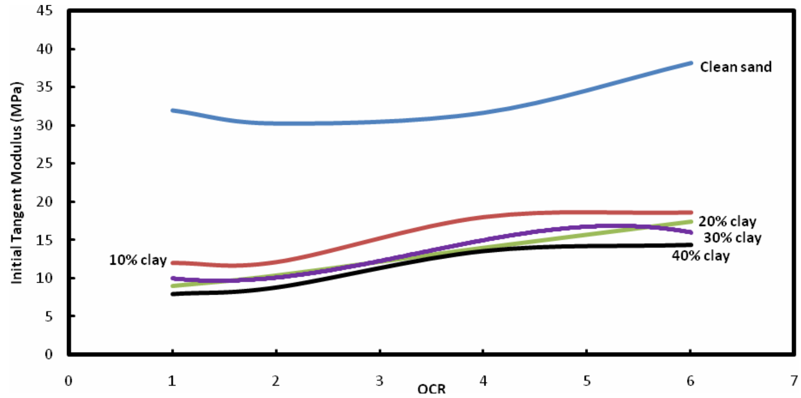


**Figure-9.** Variation of initial tangent modulus with OCR and plastic fines content.

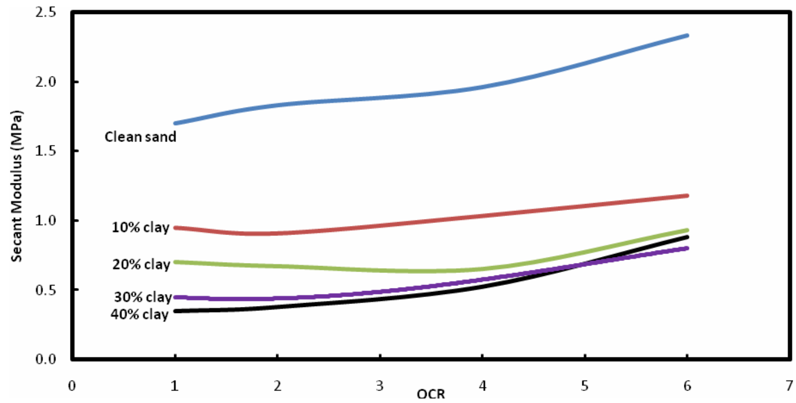


**Figure-10.** Variation of secant modulus with OCR and plastic fines content.

**(iv) Peak strength and excess pore pressure**

The normalised peak strength of the specimens decreases with increase in plastic fines content and OCR as shown in Figure-10. Its declining rate decreases when the plastic fines content is more than 20% and OCR is greater than 3. The peak strength is important because it is associated with initiation of flow deformation (Murthy *et al*. 2007 and Shelly *et al*. 1997).

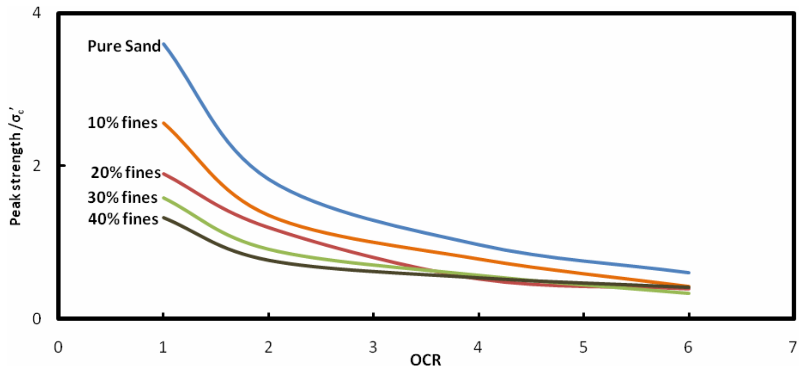


**Figure-10.** Variation of normalised peak strength with OCR and plastic fines content.

The effect of plastic fines content on excess pore pressure generation is shown in Figure-11. It is interesting to note that the maximum negative excess pore pressures are generated exhibiting dilatant tendency for clean mining sand and specimens with 10% plastic fines content. However positive excess pore pressures are generated indicating contractive response for specimens with more than 20% plastic fines content. It appears that the maximum positive excess pore pressure generation increases with increasing plastic fines content in the specimen. The addition of plastic fines weakens the soil structure because of the increase in the sand skeleton void ratio and the lubricating nature of the plastic fines. Figure-11 also shows the variation of excess pore pressure generation with OCR. The specimens with higher OCR have lower normalised maximum excess pore pressure generation. Its declining rate decreases when OCR was more than 2.

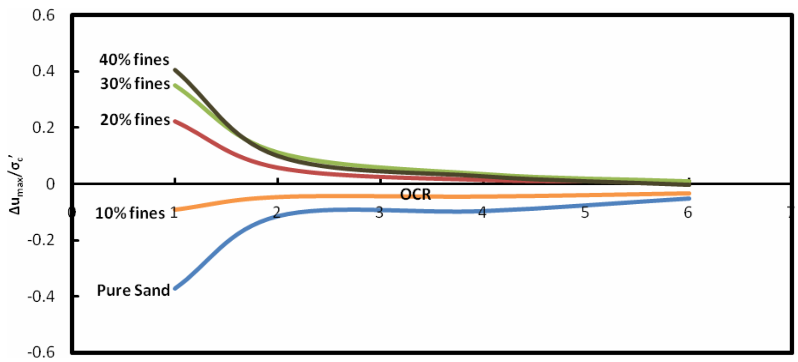


**Figure-11.** Variation of normalised maximum excess pore pressure with OCR and plastic fines content.

## CONCLUSIONS

a) High dilatancy behaviour is observed in undrained triaxial tests of over consolidated clean mining sand. However high contractive behaviour is observed for over consolidated specimens with high plastic fines content;
b) The normalised deviator stress decreases with increasing over consolidation ratio;
c) The normalised initial tangent modulus and secant modulus increase with increasing over consolidation ratio but decrease with increasing plastic fines content;
d) The normalised peak strength of the specimen decreases with increasing plastic fines content and over consolidation ratio. However its declining rate decreases when the plastic fines content is more than 20% and OCR is greater than 3; and
e) Negative excess pore pressures are generated exhibiting dilatant tendency for clean mining sand and specimens with 10% plastic fines content. However, positive excess pore pressures are generated indicating contractive response for specimens with more than 20% plastic fines content. It appears that the positive excess pore pressure generation increases with increasing plastic fines content in the specimen. The specimens with higher OCR have lower normalised excess pore pressure generation. Its declining rate decreases when OCR is more than 2.

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