TECHNICAL PAPERS

AUGER PENETROMETER DEVELOPMENT FOR THE COMPACTION CONTROL OF SAND

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SUMMARY

The Auger Penetrometer (AP) is a continuous flight auger which penetrates the soil by applying a constant static vertical load during rotary advancement. Auger resistance index (AI), is measured as the number of turns of the auger required for 100 mm depth of penetration. This paper describes an AP with a hinged handle and presents the results of experiments made to study the relation between AI and density of sand(rd), and, possible effects of operator technique and particle size on this relation. It is concluded that: (i) linear relations with strong correlations exist between log(AI) and rd of sands tested, (ii) the AP is capable of producing reproducible results for compaction control of sands, and (iii) different calibration line should be established for sands with considerably different particle size distribution.

1. INTRODUCTION

The use of direct or indirect density measurements for compaction control of sand fills is commonly adopted all over the world. Numerous methods have been developed for this purpose, including the sand replacement, rubber balloon and nuclear density meter methods. These methods disturb the soil surface and require additional laboratory testing or recalibration, but are generally considered to give reasonable to fairly accurate results.

The Auger Penetrometer (AP) was developed by Mohajerani (1982, 1985) at the University of Western Australia as an alternative approach for the determination of density of sand fills. It consists of a 22 mm diameter continuous-flight auger which cuts into the soil by applying a constant static vertical load (total weight of auger, shaft and handle = 43 Newtons) during rotary advancement. Auger resistance index (AI) is defined as the number of revolutions required for a depth of 100 mm of penetration,

i.e $$AI = 100\ NT/L \qquad (1)$$

where NT is the number of turns of the auger and L (mm) is the measured depth of penetration (about 100 - 150 mm).

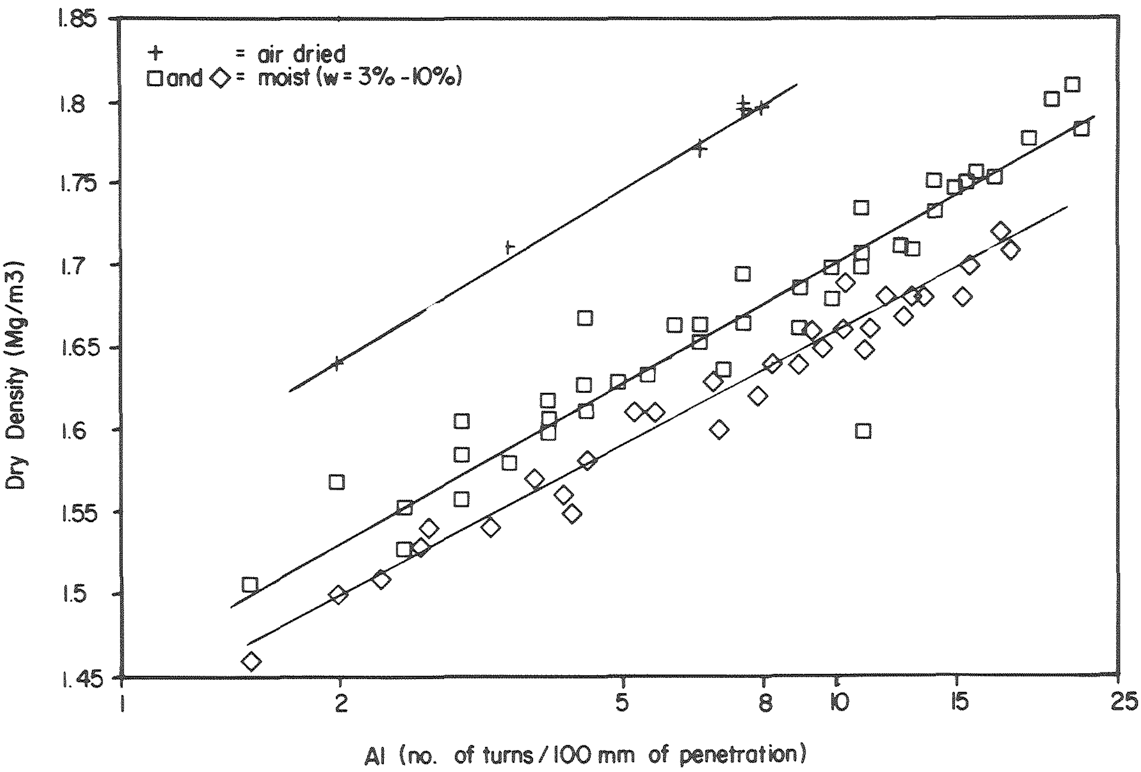

Figure 1: Correlation between dry density and log (AI)

Strong linear correlations have been found between logarithm of AI and dry density of compacted sands (Mohajerani 1982, 1985; Erceg 1982), (Fig.1). Erceg carried out parallel testing with the AP, sand replacement method and dynamic Perth Sand Penetrometer (Glick and Clegg 1965) on a compacted sand fill and found that the results from the AP method compared very favourably with the results obtained using the sand replacement method (Fig. 2). Chivers (1982) used the AP to measure the dry density of a subgrade sand and found a strong linear relationship between the modulus of subgrade reaction and the logarithm of AI (Mohajerani 1985/2).

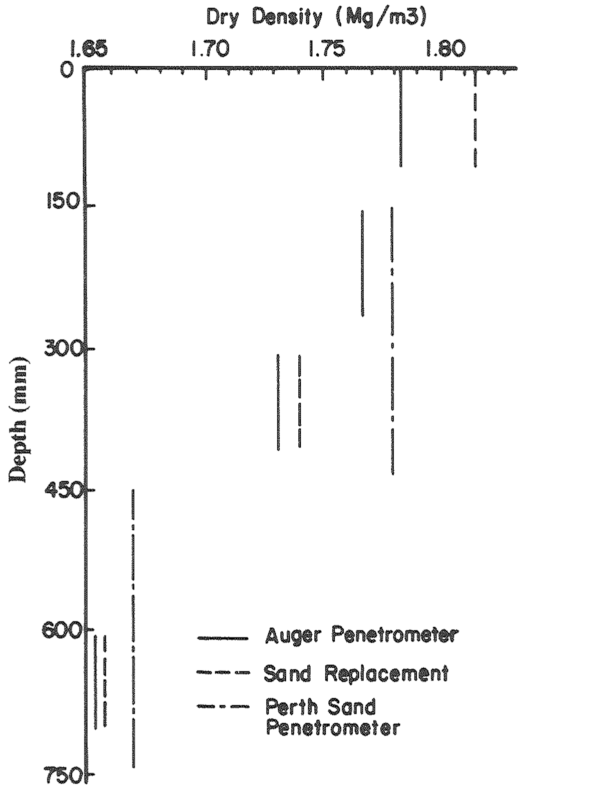

Figure 2: Comparison of the auger penetrometer, sand replacement and Perth sand penetrometer field results (Erceg 1982)

The APs used in the previous studies were equipped with fixed handle, making the penetration results dependent on the individual operators. This could explain the variation shown in Fig. 1, between the results of the two previous independent studies. It has been suggested (Mohajerani, 1985) that a more appropriate handle should be used with the AP to make it independent of operator technique.

In this study the AP was equipped with a very light (perspex) hinged handle to leave the shaft and auger free from operator influence (Fig. 3). Tests were then made to study the effect of operator technique on AI. Also, possible effects of soil particle size and auger condition on AI were investigated.

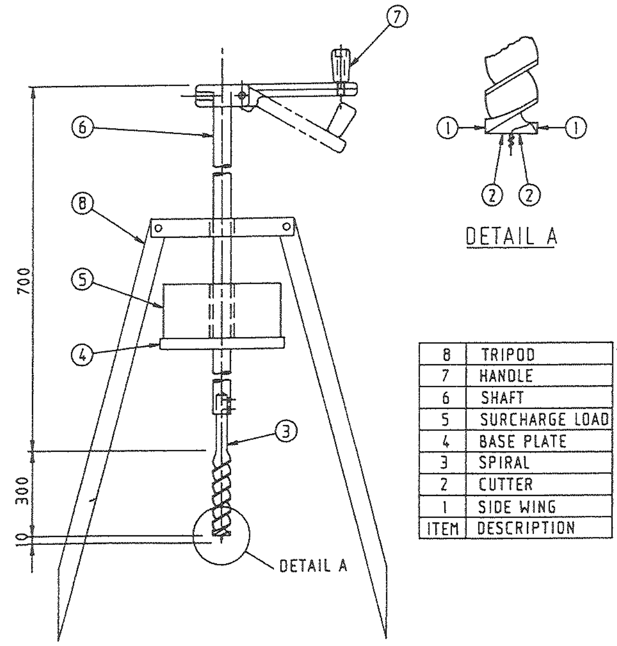

Figure 3: Auger Penetrometer (not to scale)

2. EXPERIMENTAL METHOD

Preparation for testing involved mixing a batch of sand of weighing approximately 15 kg with water to various predetermined moisture contents. Sand samples with moisture contents ranging from 1% to 12% were used to study the influence of changing moisture content on AI-density relationship. After mixing the sand thoroughly, a test specimen was prepared in a C.B.R. mould (height = 177 mm, diameter = 152 mm). It was possible to vary the density by changing the number of layers in the mould and by varying the number of blows of light or heavy standard compaction hammer per layer. The specimen was placed under the auger penetrometer and the auger lowered until the tip reached the sand surface. The shaft was released to settle under its own weight. When the auger had come to rest an initial-settlement reading was taken. The auger was then rotated slowly (at different rates of approximately 0.5 to 1.5 revolution per second) in a clockwise direction and the number of revolutions were counted until 140 mm penetration from the auger tip (127.5 mm from the cutting edge) was reached. It should be noted that, there is relatively very little disturbance around the penetrometer, with apparently no influence of the mould-edge on the penetration resistance. This is because, AP is a quasi-static method and as it penetrates, it transfers the soil through the flights.

Experiments were made by four operators: A,B,C and D, using sand A (Fig.4), and their results were compared. Operators B, C and D had not used the AP before. They were instructed to place the auger tip on the sand surface and release it slowly and when the auger has come to rest to rotate the auger slowly in a clockwise direction and to count the number of revolutions it takes to penetrate 140 mm.

Operators A,B,C and D turned the auger at different rates (rotary velocities) of approximately 1, 1.5, 1 and 0.5 revolutions per second,'respectively.

In order to examine the influence of auger condition on AI three augers were used; an auger in good condition, a rusty auger and a damaged auger. The rusty auger was prepared by etching off the lacquered surface. The auger was then left out in the weather for some months. After testing, the auger tip was then damaged by continual dropping of the auger onto a concrete floor, and the cutting edge and flight were damaged by repeated blows with a hammer.

Augers used in this study were steel augers (suitable for hardwood) with a diameter of 22.225 mm, lead of helix 50.8 mm and length of helix 300 mm (Fig. 3).

In order to study the influence of soil particle size on AI, three fine to coarse-grained, subrounded to subangular, quartzite sands were used. The grading curves are shown in Fig. 4).

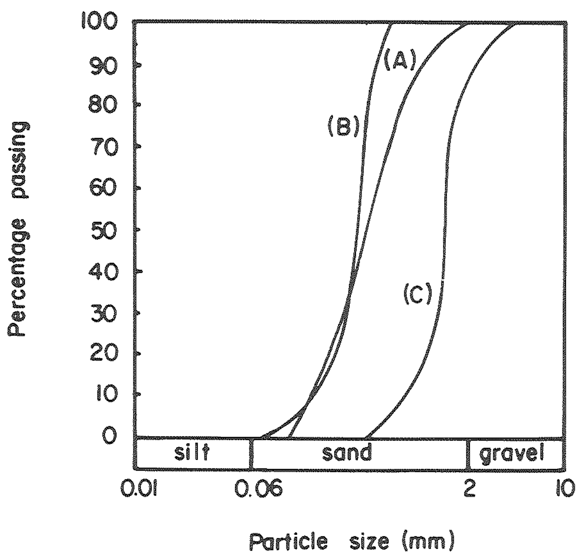

Figure 4: Grading curves of experimental sands

3. TEST RESULTS

3.1 Effect of operator

In any test method, reproducibility of the test when performed by one operator and the effect of different operator techniques on the repeatability of results are important factors.

Experiments were made to find if the AP was capable of producing reproducible results. Figs 5 shows dry density - AI and dry density - log AI relations for tests performed by the four operators, using sand A, when the moisture content of the samples ranged between 3 and 12 per cent, and the following regression equations were established:

$$\rho_d = 1.370 + 0.200 \log(AI)$$

$$(R^2 = 0.909,\ S_{yx} = 0.020,\ N = 79) \qquad (2)$$

Also, the following regression equations were established from the test results obtained by a single operator (A):

$$\rho_d = 1.362 + 0.213 \log(AI)$$

$$(R^2 = 0.936,\ S_{yx} = 0.020,\ N = 44) \qquad (3)$$

where ρ_d = dry density (Mg/m3)
AI = number of turn per 100 mm of penetration
R^2 = coefficient of determination
S_{yx} = standard error of estimate, and
N = number of cases.

Strong correlations between ρ_d and log AI for a single operator as well as for four operators, and also, relatively small changes in R2 and Syx values from eqn (2) for four operators to eqn (3) for one operator, indicate that the Auger Penetrometer is capable of producing reproducing reproducible results.

3.2 Effect of particle size

The penetrating resistance of sand to the auger is expected to be related to the particle size. To study this effect on ρ_d - AI relationship three sands, fine to coarse-grained (Fig.4), were used.

The results of tests (Fig. 5) show that particle size does influence the rd-AI relation. In order to study the extent of this influence, for the three sands tested, the following regression equations were established:

for combined results obtained using sand A and sand B (fine to medium-grained),

$$\rho_d = 1.381 + 0.199 \log(AI)$$

$$(R^2 = 0.874,\ S_{yx} = 0.023,\ N = 86), \qquad (4)$$

and for results obtained using sand C (coarse-grained),

$$\rho_d = 1.501 + 0.290 \log(AI)$$

$$(R^2 = 0.907,\ S_{yx} = 0.012,\ N = 17), \qquad (5)$$

Relatively very small changes in R^2 (0.035) and S_{yx} (0.003) values from eqn (2) for sand A and eqn (4) for sands A and B indicate that the influence of small changes of particle size on ρ_d - log(AI) relation is apparently negligible.

The results (Fig. 6 and Eqn (5)) also show that there exists a different relation, with a strong correlation, for sand C (coarse sand). This indicates that different calibration line should be established and used for sands with considerably different particle size

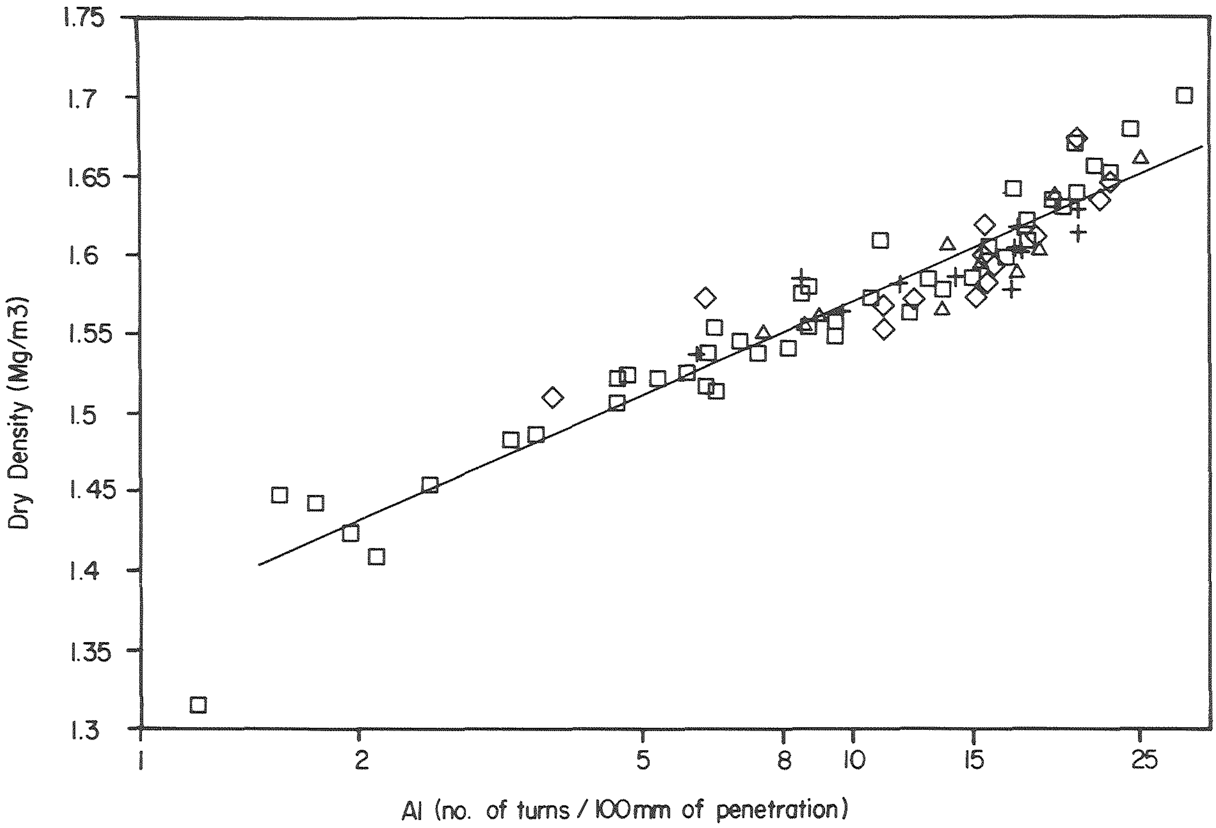

Figure 5: Effect of operator and moisture content (w) on log (AI) - ρ_d relationship (different symbols correspond to different operators)

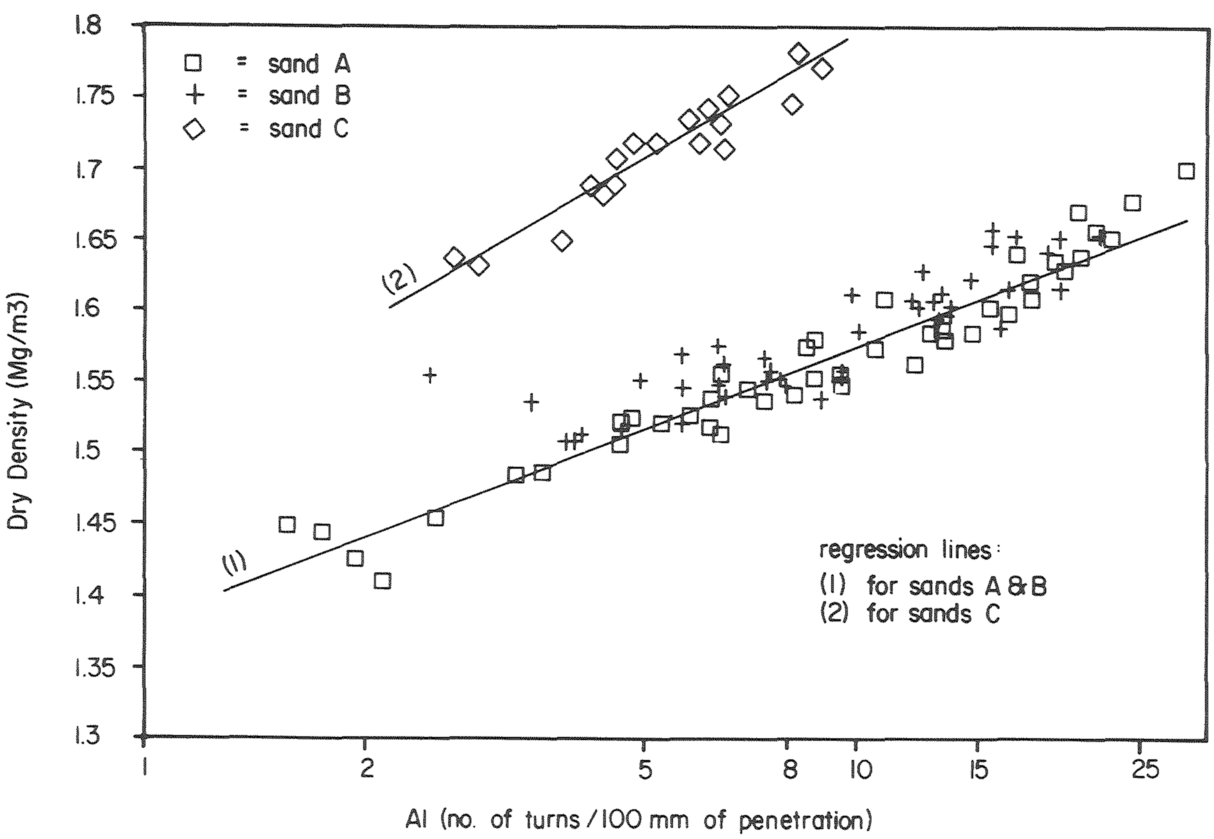

Figure 6: Effect of particle size on AI (w = 3% - 12%), Operator A

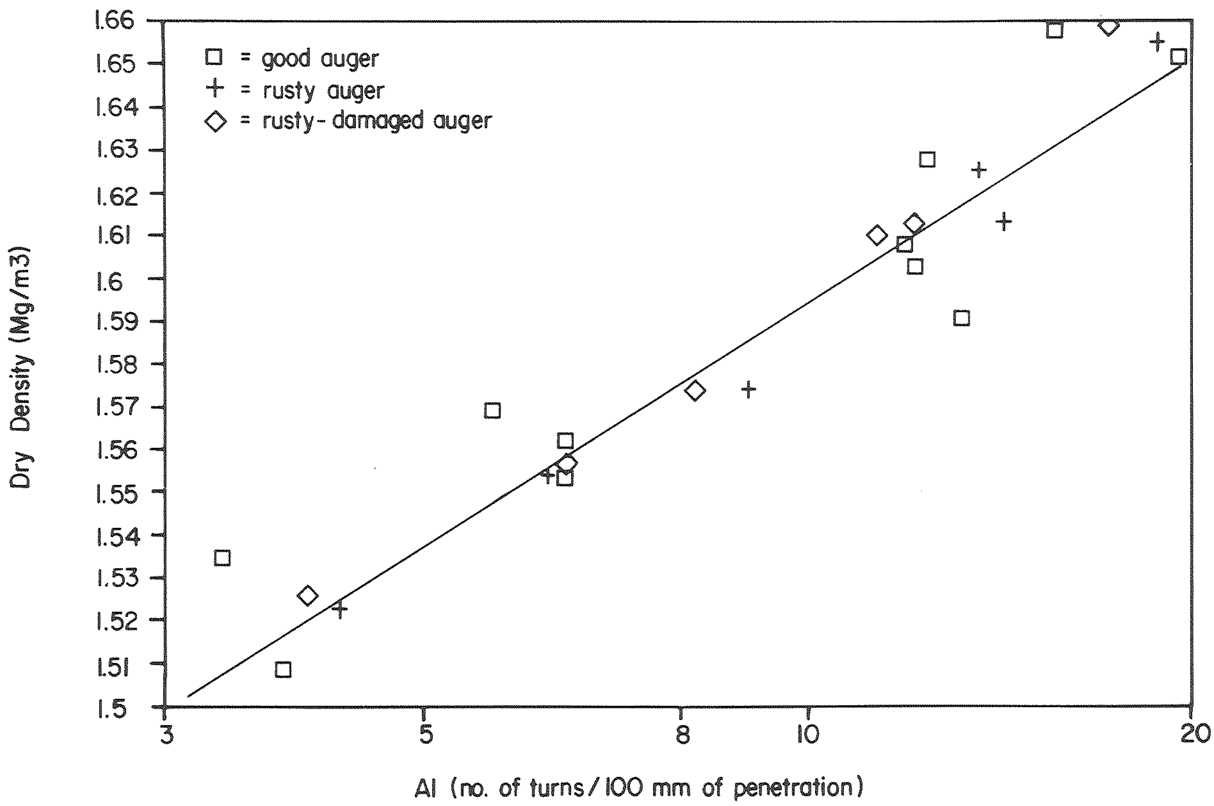

Figure 7: Effect of auger condition on AI (w = 9% - 10%)

3.3 Effect of auger condition

The surface condition of an auger might vary with continued use in the field. To examine whether the auger condition would influence the ρ_d - AI relationship, an auger in good condition, a rusty-auger and a damaged-auger were tested using sand B. The results are shown graphically on Fig.7 and the following regression equation was obtained:

$$\rho_d = 1.409 + 0.188 \log(AI)$$

$$(R^2 = 0.920, S_{yx} = 0.013, N = 23). \quad (6)$$

Fig. 7 and Eqn (6) indicate that there is apparently no or very small effect of auger surface condition on AI.

3.4 Effect of moisture content

It has been found (Mohajerani 1985) that the ρ_d - AI relationships vary for air-dried (approximately for w < 2 %) and moist conditions (Fig. 1). Under moist conditions, penetration cuts the soil, and a continuous line of chips travels through the auger flight and rises to the surface, and no significant jamming or interference takes place during the cutting process. Under dry conditions, however, penetration takes place without the formation of any cuttings, and the soil particles move against each other, the soil fills all the available room in the throat and flights of the auger, and is then transferred to the surface.

Fig. 8 shows that the effect of changing moisture content for moist conditions of sands tested is relatively small. To investigate the influence of changing moisture content, for moist conditions, the variable w was added to Eqn (2) and Eqn (3). The improvement in R^2 values and the changes in S_{xy} values were less than 0.033 and 0.005 respectively. This confirms the previous results that the effect of changing moisture content on ρ_d - AI relationship may be considered negligible, for the range of moisture contents tested.

3.5 Initial settlement of the auger

As already mentioned, AI is the number of revolution required for a depth of 100 mm of penetration. The depth of penetration could be considered including or excluding the initial settlement of the auger under the applied vertical load. Using either method does not vary ρ_d-AI relation considerably, particularly for medium to very dense conditions (Fig. 9). However, it is easier to measure the penetration depth from the commencement of turning the auger, after the initial settlement.

4. CONCLUSION

An Auger Penetrometer equipped with a hinged handle was used to investigate the relation between AI (number of turns per 100 mm of length of penetration) and ρ_d (dry density) of sand and also to study the possible effects of operator technique,

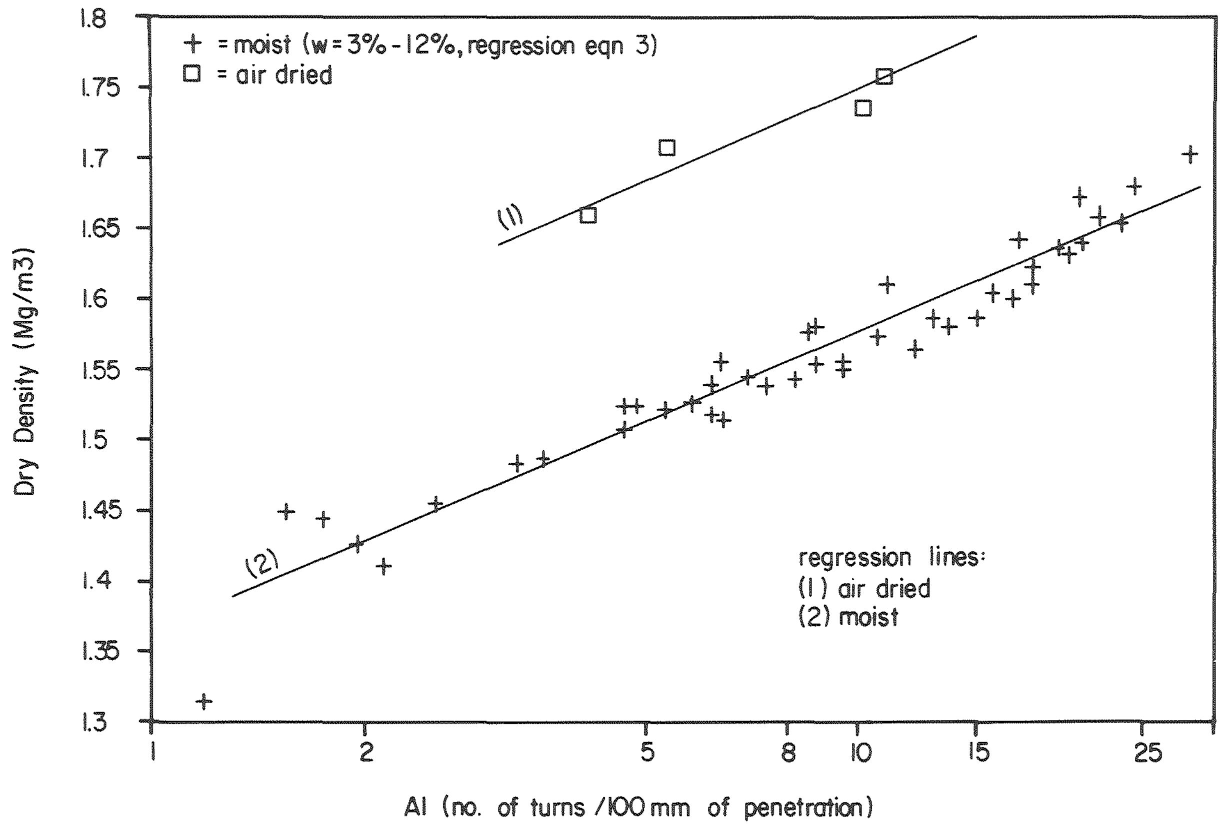

Figure 8: Effect of moisture content, sand A, operator A

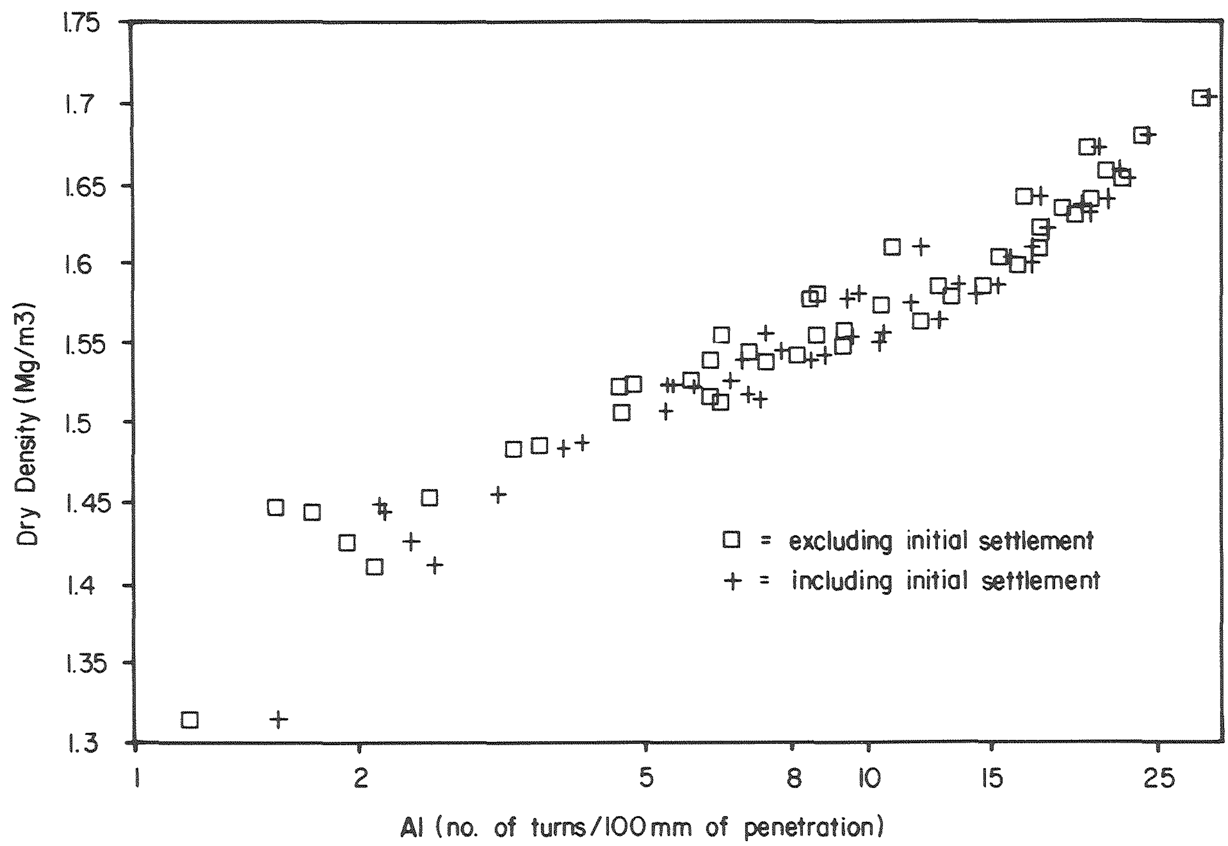

Figure 9: Effect of auger initial settlement

particle size, auger surface condition and soil moisture content on the relation.

Results show that:

1. there are strong linear correlations ($R^2 > 0.9$, $S_{yx} < 0.025$) between ρ_d and log(AI) for the 3 sands tested;

2. the Auger Penetration test is capable of producing reproducible results in sands of the same particle characteristics (viz., particle size distribution, angularity, and type), if it is used with a light hinged handle;

3. the influence of small changes of particle size on AI is apparently negligible,
4. there are different relations for sands with considerably different grain characteristics;

5. there is apparently very small effect of auger surface condition on AI, for sands tested;

6. ρ_d - AI relation vary for air-dried and moist conditions;

7. the effect of changing moisture content, for the range of moisture contents (3 - 12 %) tested, on ρ_d - AI relation is relatively small and may be considered negligible; and (8) including or excluding the initial settlement of the auger under the applied vertical load, in medium to very dense soil condition, does not vary the relation significantly. However, it is easier to measure the penetration depth from the commencement of turning the auger, after the initial settlement.

Auger Penetrometer testing can be carried out by personnel on the job to reduce the number of other more time consuming and expensive density testing control.

It offers the possibility of determining rapidly the density variation over very large areas. It is independent of laboratory testing and easy to calibrate for different sands.

5. ACKNOWLEDGMENT

The author gratefully acknowledges the efforts of the Engineers, especially Ms J. Collins, who as undergraduate students at the University of Central Queensland participated in the experimentation.

6. REFERENCES

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