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Repetitive Load Deformation Of Cohesionless Soil

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ratios, Eq. 1 is a more general expression to estimate the initial excess pore water pressure:

$$\Delta u = \Delta\sigma_{oct} \quad (34)$$

Furthermore, there are also other methods which can be used to predict the initial excess pore water pressure (9). The choice of the appropriate method, e.g., Eq. 34 or Skempton's equation, depends on the soil type, the deformation boundary condition, and the nature of the stress change.

Appendix.—References

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Repetitive Load Deformation of Cohesionless Soil[a]

Discussion by Rodney W. Lentz,[3] M. ASCE

The authors are to be congratulated for making another significant contribution to characterizing the behavior of cohesionless soil under repetitive loading. Simplified procedures for predicting accumulated permanent deformation are necessary for advancement in developing rational methods of design for railroad support structures and highway pavements.

The authors used their analysis procedure with information taken from a figure published by the writer and Baladi (7) to obtain Eq. 19 for subgrade sand with confining pressure of 35 kN/m^2 (5 psi). Apparently the small scale of the figure precluded accurate determination of the regression constants in Eq. 19. Using the actual data for this condition the writer obtained:

$$\epsilon^p = 0.00101\, e^{5.6254X} N^{0.143}; \quad \sigma_3 = 35 \text{ kN/m}^2 \text{ (5 psi)} \quad (20)$$

This data, plus data for confining pressures of 172.3 kN/m^2 (25 psi) and 344.5 kN/m^2 (50 psi), not previously published, are presented in Table 5.

Using the same procedure used by the authors, Fig. 17 was obtained showing log of first cycle plastic strain versus deviator stress level for

[a]October, 1982, by Vishnu A. Diyaljee and Gerald P. Raymond (Paper 17403).

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J. Geotech. Engrg., 1983, 109(12): 1623-1626

TABLE 5.—Log-Log Regression Results, Subgrade Sand

Sample number (1)	Repeated deviator $\sigma_1 - \sigma_3$, in kilonewtons per square meter (2)	Confining pressure σ_3, in kilonewtons per square meter (3)	Deviator stress level X (4)	Experimental plastic strain at the first cycle, as a percentage (5)	Intercept A (6)	Slope m (7)	Correlation coefficient r (8)
B3	33.5	35.0	0.231	0.00229	0.003218	0.20599	0.972
3A	68.8	35.0	0.476	0.02788	0.033261	0.12053	0.976
A3B	101.5	35.0	0.701	0.07472	0.089406	0.11121	0.973
C3	118.6	35.0	0.820	0.07784	0.098179	0.12929	0.972
D3	128.9	35.0	0.891	0.11700	0.143950	0.14714	0.972
J3	171.2	172.3	0.276	0.02344	0.026725	0.10021	0.980
F3	340.0	172.3	0.548	0.06603	0.076740	0.08556	0.969
G3	529.3	172.3	0.854	0.16880	0.210208	0.13481	0.957
H3	568.1	172.3	0.916	0.21835	0.304206	0.18212	0.947
K3	342.6	344.5	0.311	0.02844	0.032039	0.09728	0.985
L3	692.6	344.5	0.628	0.11121	0.127717	0.09765	0.975
Q3	852.2	344.5	0.773	0.20258	0.231709	0.10297	0.971
M3	978.4	344.5	0.888	0.35386	0.473373	0.15609	0.941

three confining pressures. Using the average value of m for each confining pressure and first cycle n values the following relationships were obtained for the subgrade sand:

$$\epsilon^p = 0.00945\, e^{3.4214X} N^{0.126}; \quad \sigma_3 = 172.3 \text{ kN/m}^2 \text{ (25 psi)} \quad \text{(21)}$$

$$\epsilon^p = 0.00733\, e^{4.3355X} N^{0.114}; \quad \sigma_3 = 344.5 \text{ kN/m}^2 \text{ (50 psi)} \quad \text{(22)}$$

Comparing the average m values for each confining pressure indicates that m decreases with increasing confining pressure which is in agreement with Fig. 5.

Plastic stress-strain curves obtained from Eqs. 20, 21, and 22 for 10^4 cycles is shown plotted in Fig. 18. Excellent agreement between predicted and experimental strains were obtained for confining pressures of 172.3 kN/m^2 (25 psi) and 344.5 kN/m^2 (50 psi) for stress levels below 60% of the failure stress. The results for confining pressure of 35 kN/m^2 (5 psi) show poor agreement between predicted and experimental strains.

The writer and Baladi (19) have suggested an alternative procedure for predicting plastic strains in subgrade sand under repetitive loading. Based on cyclic triaxial test results a constitutive equation was developed, which for a given sand accounts for density, confining pressure and cyclic deviator stress. The writer found that for the subgrade sand a semilogarithmic (ϵ^p versus log N) relationship provided higher coefficients of correlation than did log-log. This allowed the following equation to be used:

$$\epsilon^p = a + b \ln N \quad \text{(23)}$$

in which a and b = regression constants representing plastic strain during the first cycle and the slope of the plastic strain versus ln N curve,

J. Geotech. Engrg., 1983, 109(12): 1623-1626

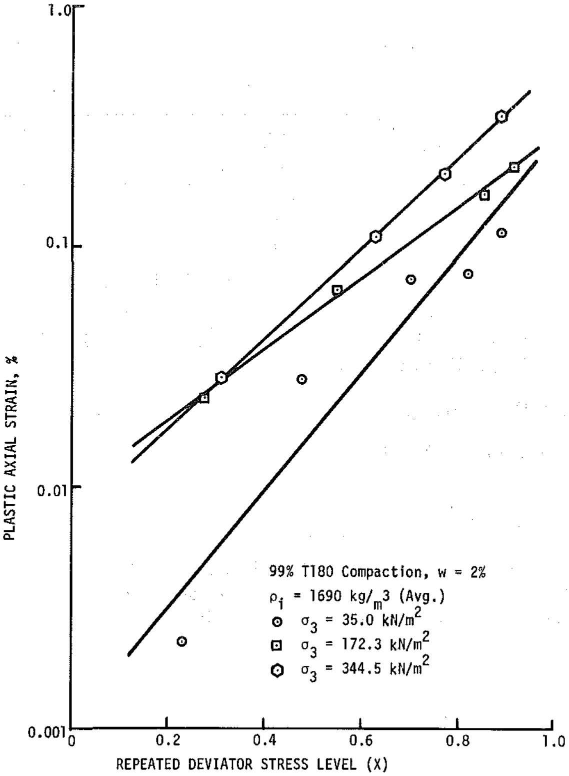

FIG. 17.—Subgrade Sand: Logarithm of Plastic Axial Strain at Cycle One versus Stress Level

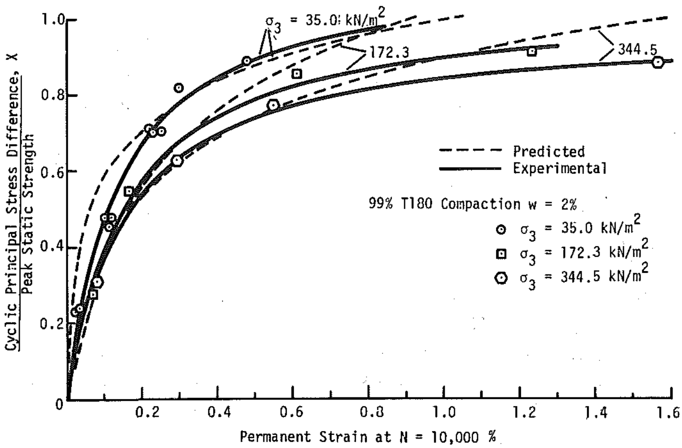

FIG. 18.—Subgrade Sand: Comparison of Predicted and Experimental Plastic Strain at 10^4 Cycles

respectively. The parameters a and b were then normalized using parameters obtained from static stress-strain curves. The resulting equation is

$$\epsilon^p = \epsilon_{0.95S_d} \ln\left(1 - \frac{\sigma_d}{S_d}\right)^{-0.15} + \frac{\left(\dfrac{\sigma_d}{S_d}\right) n \ln N}{1 - m\left(\dfrac{\sigma_d}{S_d}\right)} \quad \text{(24)}$$

in which σ_d/S_d is the same as X used by the authors; $\epsilon_{0.95S_d}$ = a reference strain from a static stress-strain curve; and m and n = regression constants (not the same as m and n used by the authors). The values of m and n are functions of confining pressure.

$$m = 0.8564 + 0.04965 \ln \sigma_3 \quad \text{(25)}$$

$$n = (0.8094 + 0.00377\,\sigma_3) \times 10^{-2}\% \quad \text{(26)}$$

Appendix.—Reference

19. Lentz, R. W., and Baladi, G. Y., "Constitutive Equation for Permanent Strain of Sand Subjected to Cyclic Loading," *Transportation Research Record No. 810*, Transportation Research Board, 1981, pp. 50–54.

Discussion by W. O. Yandell[4] and I. K. Lee[5]

The authors have made a very useful contribution to the understanding of repeated load behavior of soils. Their suggestions will reduce the need for large numbers of repeated load tests at various confining stresses on some soils. We would like to make three points:

1. Data plotted in Fig. 4 of their paper establishes quite convincingly linear relationships between log plastic axial strain and log number of load repetitions. On many soils such linearity is only achieved after about 100 cycles.
2. Yandell, to predict rutting in a test track, used only five load repetitions of in-situ repeated bearing tests. One step in the prediction process was to plot the five permanent strain values on log-log plots for each of four tests. The results shown in Fig. 19 reveal the precise linear relationship.
3. It also seems very likely that if the authors had pulsed their cell pressures in phase with their repeated deviation stresses they would again have established straight and almost parallel lines in Fig. 5. It would be anticipated that lines for each value of $X = (\sigma_1 - \sigma_3)/(\sigma_1 - \sigma_3)f$ would have been closer together since, for example, the material in the X =

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J. Geotech. Engrg., 1983, 109(12): 1623-1626