RESEARCH NOTE

RELATIONSHIP BETWEEN GROUND SETTLEMENT DUE TO TUNNELLING AND GROUND PHYSICO-MECHANICAL PROPERTIES

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Abstract Over the past few decades much research has been done on ground settlement due to underground excavations in soft ground. One objective has been to find some relationships between settlement characteristics and physico-mechanical properties of the ground. The objective of this paper is to present, on the basis of existing experimental data, the parameters upon which settlement characteristics are believed to depend.

Key Words Tunnel, Soft Ground, Ground Properties, Ground Deformation, Relative Settlement

چکیده در دهه های اخیر، مطالعات زیادی پیرامون «نشست زمینهای غیرسنگی دراثر حفر تونل در آنها» صورت گرفته است، بخشی ازاین مطالعات درجهت تعیین رابطه هایی بین مشخصات نشست و خواص فیزیکی - مکانیکی زمین است، دراین مقاله، درمورد ارتباط مقدار نسبی نشست زمین با ویژگیهای فیزیکی - مکانیکی زمین بحث می شود و براساس اطلاعات تجربی چاپ شده درمقالات، فرم ریاضی بیان این ارتباطها پیشنهاد می گردد.

INTRODUCTION

The Subject of ground settlement due to tunnelling in soft ground has been well researched [1]. The majority of research done on this subject can be divided into three main categories, namely, studies involving:

1) Laboratory model tests [2-7]

2) Real scale cases [6, 13-15]

3) Theoretical investigations [1,10,16-18].

Most of the above mentioned studies concern the following:

1) The relationship between settlement, its distribution and relative settlement (S_{max}/D) with the depth and diameter of the tunnel [1,5,10,13,16,18-21], as well as with the deformation of the tunnel cross-section [1,16,22].

2) The relationship between ground settlement characteristics with ground physico-mechanical properties, namely, soil cohesion, soil unit weight, overconsolidation ratio, and water content [1,16,20,23].

EFFECT OF SOIL PROPERTIES, DEPTH AND DIAMETER OF THE TUNNEL ON GROUND SETTLEMENT

According to the literature, it is now possible to estimate the effect of each parameter. The influential factors will be outlined briefly.

a) Soil choesion (c) is a strength factor and its effect on ground settlement is similar to that of modulus of elasticity. Consequently, less deformation is expected as the amount of choesion increases. The effect of soil cohesion is illustrated in Figures 1-4.

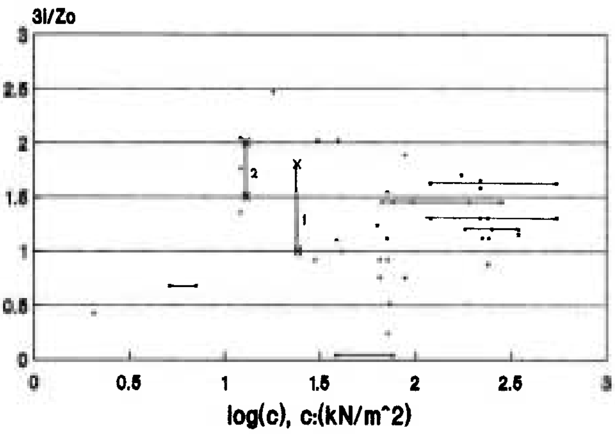
b) Deformation modulus (E) is another strength factor, and it can therefore be concluded that as the value of the deformation modulus increases, the amount of deformation decreases. To evaluate the value of this parameter on the settlement ratio, a dimensionless number $E/\gamma D$ is applied. The effect of applying this number is illustrated in Figures. 5 and 6.

c) Ground unit weight (γ) is the main factor that causes ground deformation above the tunnel and its effect is shown in Figures 2-6.

d) Depth (z_o) and diameter (D) of the tunnel are two other factors that are generally considered to be significant parameters affecting settlement evaluation (see Figures 2-6).

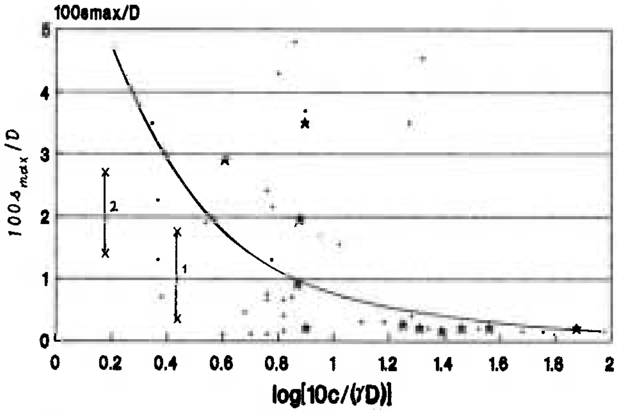
SEARCHING FOR RELATIONSHIPS

To examine the experimental data for empirical relationships, the values of appropriate parameters are taken from the available literature and adjusted to



• Reference 1, pp. 9-22(full scale cases); × Reference 9, (1: from 23 to 504 days 2: from 4 to 1000 days).

Figure 1. Correlation of trough width ($3i/z_o$) with soil cohesion



References are the same as in Figure 1.

× Reference 9 * Reference 16 • Reference 1

Figure 2. Dependence of the relative surface settlement upon $c/\gamma D$.

the suitable coordinate axes, as shown in Figures 1-6.

The results are as follows:

1) Based on References 1 and 9, Figure 1 is presented, so that the ordinate axis is log (c) and the abscissa is $3i/z_o$. The abscissa of the graph is chosen as $3i/z_o$ because the width of the settlement trough is usually expressed by the parameter i (inflexion point of Peck,s empirical formula, [19] and the end of the trough width is taken as 2.5i-3i.

Figure 1 shows no obvious correlation between the width of the settlement trough and the amount of

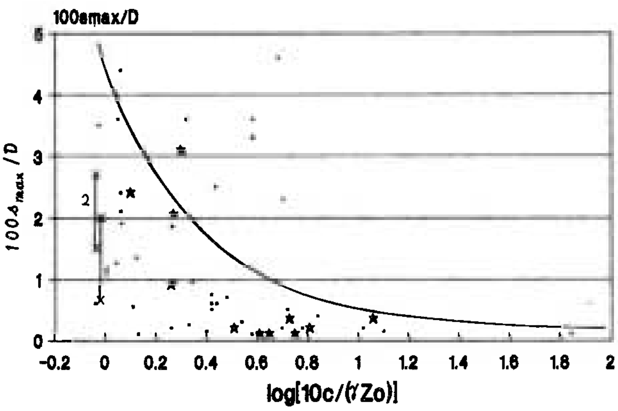


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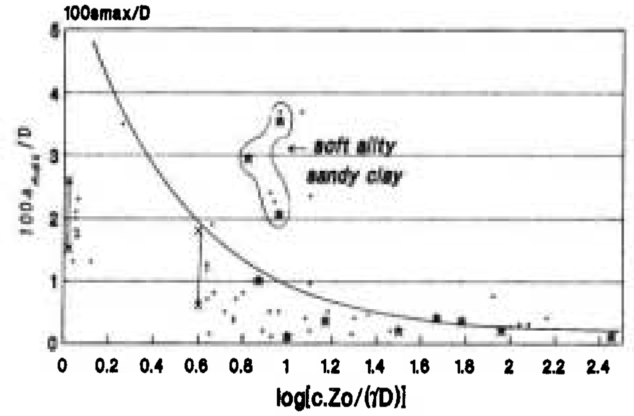
Figure 3. Dependence of the relative surface settlement upon $c/\gamma z_o$.



References. are the same as in Figure 1.

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Figure 4. Dependence of the relative surface settlement upon $cz_o/(\gamma D)$.

soil choesion. This result was expected because the effect of cohesion is apparent only when the shear strength is mobilized, whereas the ground settlement over the tunnel is within the range of elastic or semi-elastic deformation, which is quite different from shear strength mobilization.

2) To evaluate the effect of other influential factors, the values of η = 100 S_{max}/D (in percent) are shown against the values of $x_1 = \log(10c/\gamma D)$, $x_2 = \log(10c/\gamma z_o)$ and $x_3 = \log(c.z_o/\gamma D)$ on Figures 2,3 and 4, respectively.

As expected, the relative settlement (S_{max}/D) decreases as unit weight and tunnel diameter increase. Based on these figures, the following formulae are proposed to account for the curves showing the best relationships of the values η to x_1, x_2, x_3:

$$\eta = \frac{1}{0.15 + 1.2\,x_1^2}\ ,\quad \eta = \frac{1}{0.15 + 1.2\,(x_2 + 0.2)^2}\ ,\quad \eta = \frac{1.25}{0.25 + x_3^2}$$

3) The relationship between the ratio $\lambda = S_{max} / S_c$ and the values of $\log(E/\gamma D)$ and $\log(Ez_o/\gamma D)$ are illustrated in Figures 5 and 6. It is concluded from these figures that the ratio λ is clearly dependent upon the values of γ, E, D and z_o.

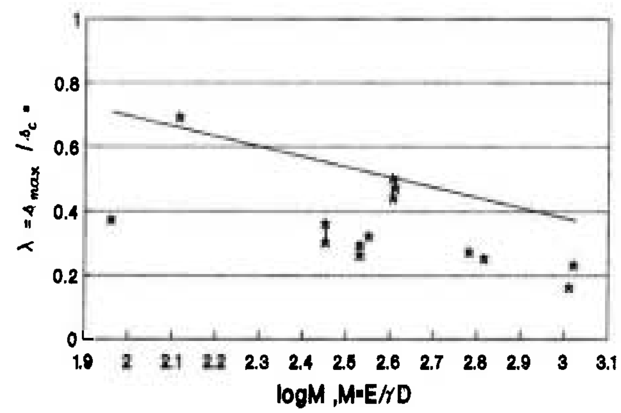
Based on these correlations, the following empirical formulae may be proposed for the upper limits:

$$\lambda = 1.4 - 0.35 \log(E/\gamma D)$$

$$\lambda = 0.76 - 0.3 \log(Ez_o/\gamma D)$$

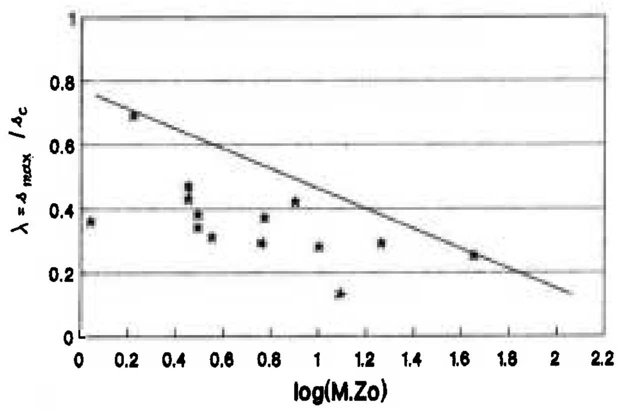
CONCLUSION

There are sufficient data from the existing literature to propose formulae for determining appropriate relationships between ground settlement characteristics and ground properties, as well as with tunnel diameter and depth. These empirically-based



* Data from Reference 16

Figure 5. Dependence of the Settelement ratro upon $E/\gamma D$.



* Data from Reference 16

Figure 6. Dependence of the settelement ratio upon $E.z_o/\gamma D$.

correlations may be expressed by some suitable empirical formulae that are useful for estimating the possible amounts of the relative or absolute ground settlement due to shallow tunnelling in soft ground.

More experimental data and theoretical analyses are needed in order to make much more precise equations possible.

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ABBREVIATION

z_o, (m): depth of tunnel centre;
D = 2a, (m): tunnel diameter;
S_{max} , (m): maximum settlement on ground surface;
S_c, (m): maximum deformation at the tunnel roof;
i , (m): horizontal distance of inflexion point of settlement trough from the vertical axis;
c, (kN/m^2): soil choesion;
E, (kN/m^2): modulus of elasticity;
γ, (kN/m^3): ground unit weight;
$M = E/\gamma D$, (non-dimensional): Firmness number, proposed in the present paper;

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