Kansai International Airport. Theoretical settlement history

Aéroport international de Kansai. Historique théorique du tassement

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ABSTRACT: The settlements measured in the last eight years 2004-2011 in the Kansai International Airport are compared with the theoretical curve provided by the Principle of Natural Proportionality and published by the author in the 16th International Conference on Soil Mechanics and Geotechnical Engineering, Osaka 2005, in the paper"Kansai International Airport, future settlements".

RÉSUMÉ : Les tassements mesurés au cours des huit dernières années 2004-2011 sur le site de l'aéroport international de Kansai sont comparés avec la courbe théorique fournie par le principe de proportionnalité naturelle et publiée par l'auteur dans la 16e Conférence internationale de Mécanique des Sols et de la Géotechnique, Osaka 2005 : le papier "Aéroport International du Kansai, les tassements futurs".

KEYWORDS: Principle of Natural Proportionality, Kansai International Airport, settlement.

1 INTRODUCTION

“Kansai International Airport, future settlements” is the title of a paper presented by the author in the 16th International Conference on Soil Mechanics and Geotechnical Engineering, Osaka 2005, where the Principle of Natural Proportionality (Juárez-Badillo 1985b) was applied to the settlement data already published of the airport, to obtain the theoretical equation of its settlement.

In Juárez-Badillo (2005) is mentioned that the general equations provided by the principle of natural proportionality (Juárez-Badillo 1985 b), have been proven to describe the mechanical behavior of geomaterials: solids, liquids and gases. They have been applied to describe the stress strain time temperature relations of rocks, granular and fine soils and concrete (Juárez-Badillo 1985 a, 1988, 1997 a, 1999 a, 1999 b, 1999 c, 2000, 2001). A general equation for the evolution of settlement of engineering works has already been applied to the settlement data of embankmens, they are the settlements for the accommodation building (A) at Gloucester (Juárez-Badillo 1991) and to the settlements in the Fraser River delta (Juárez-Badillo 1997 b). This time this general equation is applied to the experimental data of the Kansai International Airport built in an artificial island 5 km from Osaka in Japan.

2 GENERAL TIME SETTLEMENT EQUATION

Consider an engineering work like an embankment that applies a load at the soil at time t=∞. The settlement S will increase from S=0 at t=0 to a total value $S=S_T$ at t=∞. These concepts S and t are the simplest concepts to describe the phenomenon, that is, they are proper variables. The relationships between them, according to the principle of natural proportionality, should be through their proper functions, that is, the simplest functions of them with complete domains, that is, functions that vary from 0 to ∞. The simplest function of S and t with complete domainare $z=1/S-1/S_T$ and t. When t varies from 0 to ∞, z varies from ∞ to 0. The principle of natural proportionality states that the relationships between them should be (Juárez Badillo, 2010):

$$\frac{dz}{z} = -\delta \frac{dt}{t} \qquad (1)$$

where: δ is the coefficient of proportionality called the “fluidity coefficient”

integration of (1) gives

$$\mathbf{Z}^{\delta} = \text{constant} \qquad (2)$$

which may be written

$$\left(\frac{S_T}{S} - 1\right) t^{\delta} = \text{constant} = \left(t^*\right)^{\delta} \qquad (3)$$

where $t^*=t$ at $S=1/2S_T$ and we may write

$$S = \frac{S_T}{1 + \left(\frac{t}{t^*}\right)^{-\delta}} \qquad (4)$$

Figs. 1 and 2 show the graphs of (4) for different values of δ in natural and semi-log plots respectively. From Fig. 1 we may observe that it appear that we should have $\delta \leq 1$.

Juárez Badillo (2005) specify that the parameter values to be obtained are S_T, δ and t*. They may be obtained from good experimental points. The author prefers, however, to obtain them from semi-log plot, Fig. 2. It can be shown (Juárez Badillo 1985 a) that the middle third of the settlements S_T is practically very close to a straight line. So, if one is able to determine from the settlement data the beginning of this straight line, one is able to determine the three parameters since this straight line extends l cycles in the graph, where

$$\frac{0.6}{\delta} = l \text{ cycles} \qquad (5)$$

From (4) it may be obtained the slope at t=t* as

$$\left(\frac{dS}{d\,log t}\right)_{t=t^*}=\frac{2.3}{4}\delta S_T \tag{6}$$

and the settlement rate, from (4) is given by

$$\left(\frac{dS}{dt}\right)=S_T\frac{\delta}{t}\frac{\left(\frac{t}{t^*}\right)^{-\delta}}{\left[1+\left(\frac{t}{t^*}\right)^{-\delta}\right]^2} \tag{7}$$

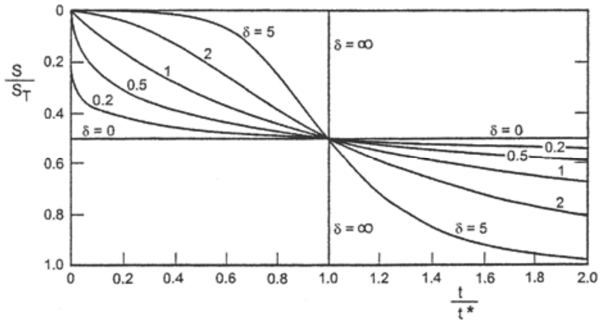

Figure 1. Graphs of $\frac{S_T}{S}=\left[1+\left(\frac{t}{t^*}\right)^{-\delta}\right]^{-1}$

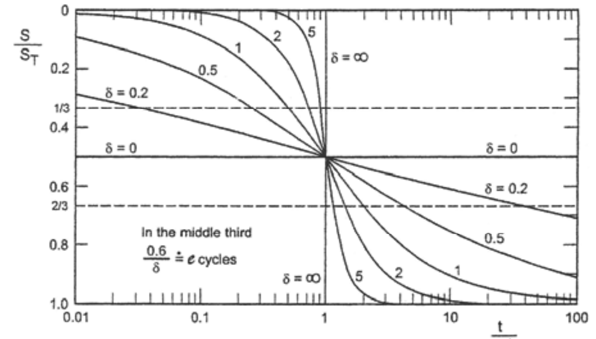

Figure 2. Graphs of $\frac{S}{S_T}=\left[1+\left(\frac{t}{t^*}\right)^{-\delta}\right]^{-1}$

3 KANSAI INTERNATIONAL AIRPORT

The Kansai International Airport was built in an artificial island 5 km from Osaka, Japan (Juárez Badillo, 2005). Fig. 3 shows the experimental compressibility curve (Tsuchida 2000) of undisturbed Pleistocene clay to which is attributed any further settlements. Its compressibility coefficient γ in the general equation (Juárez Badillo 1969).

$$\frac{V}{V_1}=\frac{1+e}{1+e_1}=\left(\frac{\sigma}{\sigma_1}\right)^{-\gamma} \tag{8}$$

where γ=0.19 and (σ_1,e_1) is a known point. Fig. (3) shows the theoretical points from (8). The laboratory quasi OCR=1.0-1.5 and the predicted settlement was 11.6 m calculated following the traditional way of calculation (Tsuchida 2000). The traditional coefficients m_v and C_c at any point are given by

$$m_v=\frac{\gamma}{\sigma_v} \tag{9}$$

$$C_c=2.3\gamma(1+e) \tag{10}$$

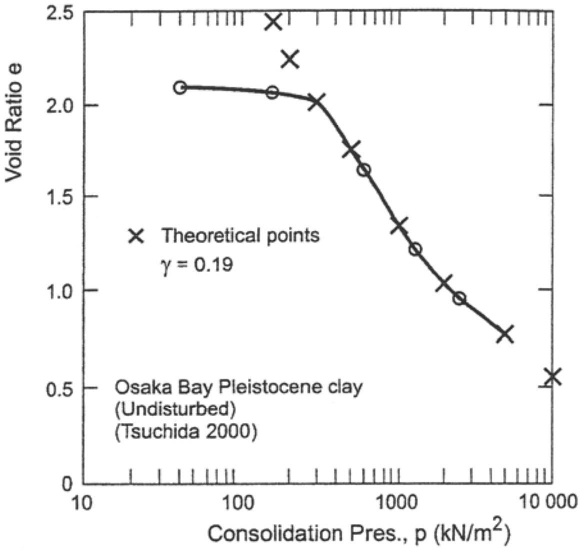

Figure 3.e-log p curve of undisturbed Pleistocene clay

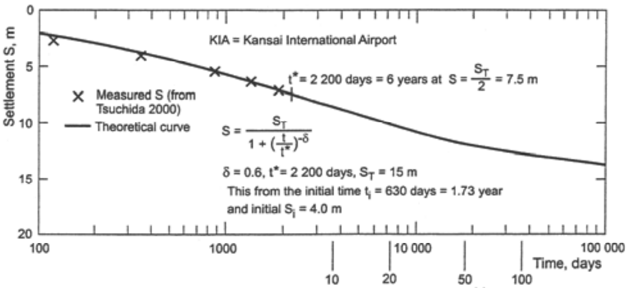

Figure 4.Settlements in KIA island

The construction of KIA started by Sept. 1987 and the opening of the Airport was seven years later, by Sept. 1994 when the first phase of construction was complete. During the period of construction from about the day 530 to about the day 630 the overburden stress by reclamation increased from about 200 to 450 kPa. By the day 1,300 the applied total load increased to about 500 kPa (Tsuchida 2000). The author took as origin of the final stage of construction the initial time t_i=630 days, (when the 90% of the total load was already in place), with an initial settlement S_i=4.0 m. Figs. 4 and 5 show application of (4) and (7) to this important case. As mentioned above the origin of time for these figures is around year 1989 and application of (4) and (7) for the present year 2004 (t=15 years) gives a total settlement of 9.50+4=13.50 m and a settlement rate of 14 cm/year. The total settlement at t=∞ will be S_T=15+4=19 m. In Fig. 5 the times from the considered initial time, year 1989, appear in parenthesis (Juárez Badillo 2005).

Fig. 5 presents also in this paper the eight settlement rates corresponding to the last eight years 2004 to 2011. As may be observed they are tending towards the theoretical curve.

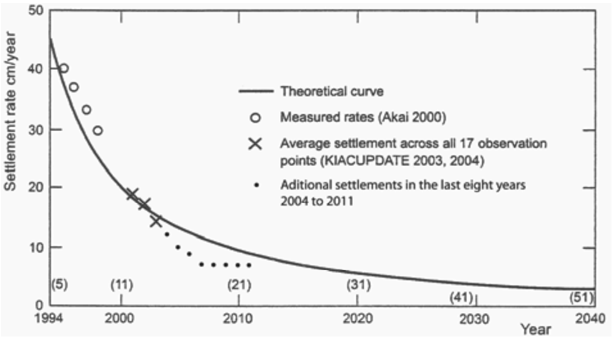

Figure 5.Settlements in KIA Island

4 CONCLUSIONS

Juárez Badillo (2005) maintain that the magnitude and evolution of the settlement of embankments in practice are described by the general equation (4). The total settlement S_T may be obtained from the EOS (end of secondary) compressibility curve (Juárez Badillo 1988) of the subsoil using the compressibility coefficient γ in equation (8) for its determination. The fluidity coefficient δ and the characteristic time t* require, at present, experimental test fills to study the factors that influence their values in a certain place. A very important point is to have a clear distinction between the two compressibility curves: the EOP (end of primary) and the EOS (end of secondary). Quasi OCR of 1 to 1.8 in practice correspond to a true OCR=1 in many cases. The difference has been illustrated in this paper by the application of Eq. (4) to the important case of the Kansai International Airport.

The important conclusion for this paper is precisely the fact that the settlement rate in the last eight years tend towards the theoretical curve obtained by the Principle of Natural Proportionality.

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