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Kansai International Airport, future settlements

Les tassements futures de L´aéroport International de Kansai

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ABSTRACT
The general equation provided by the Principle of Natural Proportionality (PNP) for the evolution of the settlement of embankments is applied to the experimental data of the Kansai International Airport (KIA) built in an artificial island 5 km from Osaka in Japan. The general equations provided by the PNP have been proven to describe the mechanical behaviour of geomaterials: solids, liquids and gases. They have been applied to rocks, concrete and granular and fine soils. The application of this general equation to the settlement data of a friction–piled box foundation in Mexico City clay is also included.

RESUMÉ
L´équation générale dérivée du Principe de la Proportionnalité Naturelle (PPN) concernant l'évolution des tassements de remblais a été appliquée aux résultats expérimentaux de l'aéroport international de Kansai construit sur une île artificielle qui se trouve à 5 kilomètres de la ville d´Osaka à Japon. Les équations générales dérivées du PPN ont été prouvées en matériaux solides, liquides et gazeux, en ce qui concerne leur description mécanique. Les mêmes équations ont été aussi appliques aux roches, béton, sols fins et sols granulaires. Cette équation générale a été en plus appliquée aux résultants expérimentaux concernant une fondation avec des pieux à frottement dans les sols argileux de la ville de Mexico.

1 INTRODUCTION

The general equations provided by the principle of natural proportionality (Juárez-Badillo 1985 b), have been proven to describe the mechanical behaviour 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 the settlement of engineering works has already been applied to the settlement data of embankments, they are the settlement 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. The application to a friction-pile box foundation in Mexico City clay is also included. For the sake of completeness this general equation is briefly obtained.

2 GENERAL TIME-SETTLEMENT EQUATION

Consider an engineering work like an embankment that applies a load at the soil at time $t = 0$. The settlement S will increase from S = 0 at $t = 0$ to a total value $S = S_T$ at $t = \propto$. These concepts S and t are the simplest concepts to describe the phenomenon, that is, they are proper variables. The relationship 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 $\propto$. The simplest functions of S and t with complete domains are $z = 1/S - 1/S_T$ and t. When t varies from 0 to $\propto$, z varies from $\propto$ to 0. The principle of natural proportionality states that the relationship between them should be:

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

where δ is the coefficient of proportionality called the "fluidity coefficient".

Integration of (1) gives

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

which may be written

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

where $t^* = t$ at $S = ½ S_T$ 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 appears that we should have $\delta \leq 1$.

The parameter values to be obtained are S_T, δ and t^*, They may be obtained from three good experimental points. The author prefers, however, to obtain them from the semi-log plot, Fig. 2. It can be shown (Juárez-Badillo 1985 a) that the middle third of the settlement 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

$$\frac{0.6}{\delta} = \ell \text{ cycles} \tag{5}$$

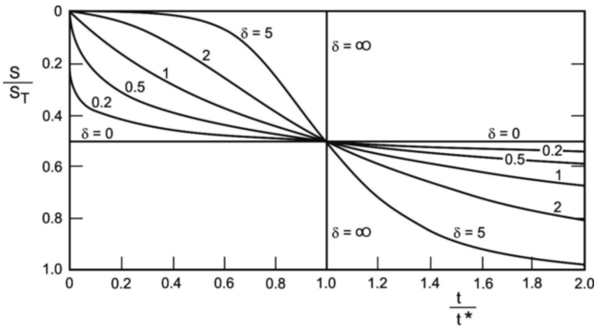

Fig. 1. Graphs of $\frac{S}{S_T} = \left[1 + \left(\frac{t}{t^*}\right)^{-\delta}\right]^{-1}$

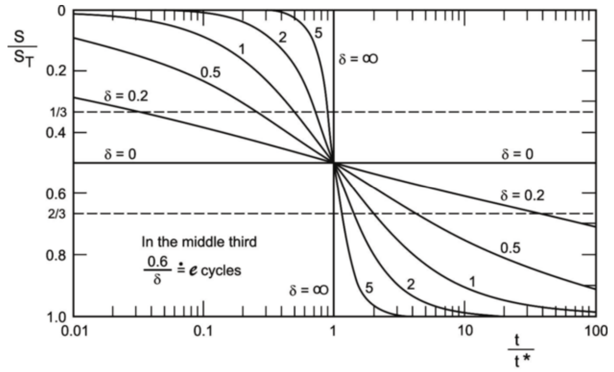

Fig. 2. Graphs of $\frac{S}{S_T} = \left[1 + \left(\frac{t}{t^*}\right)^{-\delta}\right]^{-1}$

This procedure was followed by the author in the two cases that are presented in this paper.

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

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

3 KANSAI INTERNATIONAL AIRPORT

The Kansai International Airport was built in an artificial island 5 km from Osaka, Japan. 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)

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

is $\gamma = 0.19$ 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

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

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

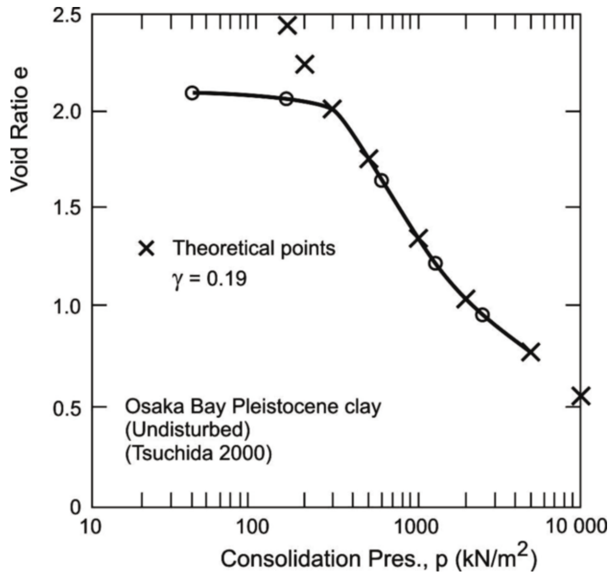

Fig. 3. e-log p curve of undisturbed Pleistocene clay

The construction of the 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 completed. 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 $t = \infty$ will be S_T = 15 + 4 = 19 m. In Fig. 5 the times from the considered initial time, year 1989, appear in parenthesis.

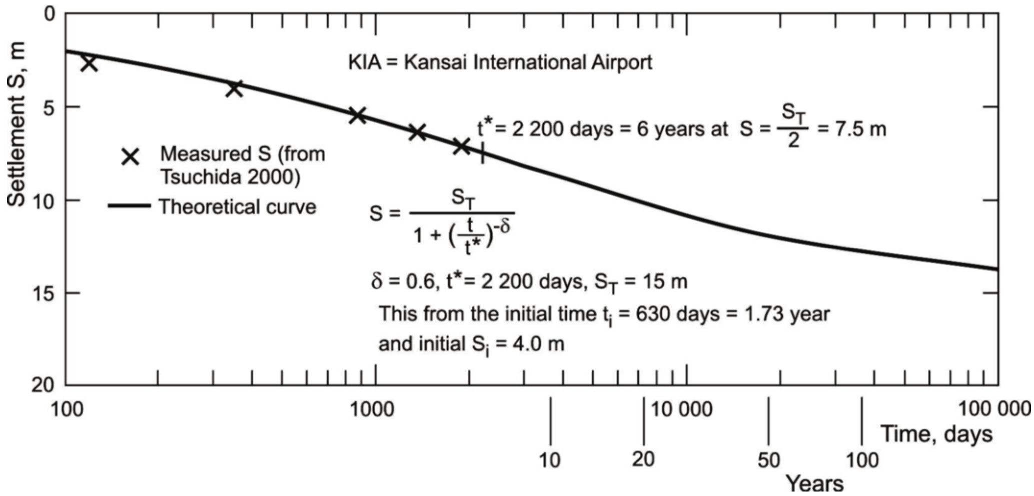

Fig. 4. Settlement in KIA island

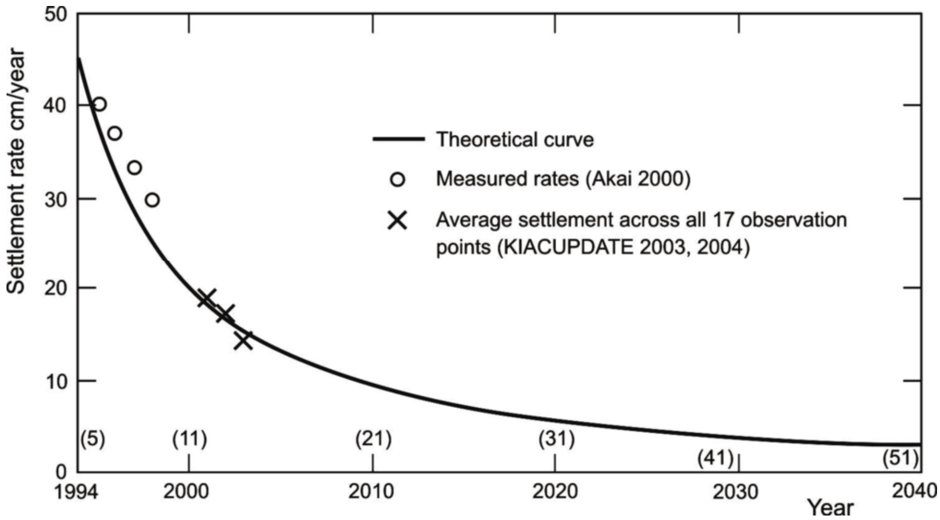

Fig. 5. Settlement rate of KIA

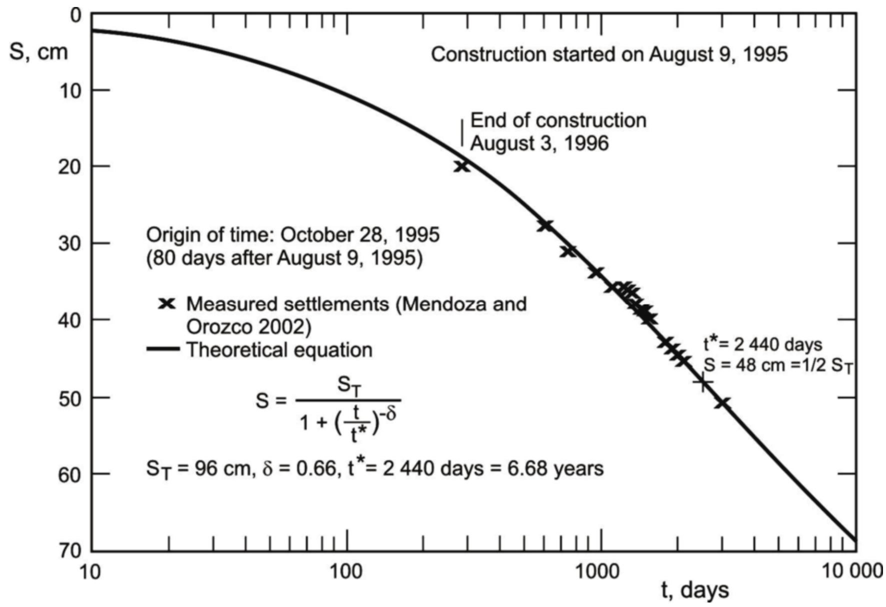

Fig. 6. Settlements in friction-piled box foundation

The Japanese are involved at present in the construction of the KIA second phase in a second larger new artificial island by reclamation and have already predicted a total settlement of 18 m (Tsuchida 2000). For the author, taking into account the above presentation, the total settlement of the KIA second phase will be much grater.

4 FRICTION-PILED BOX FOUNDATION

A friction-piled box foundation in Mexico City clay, the foundation of a vehicular-bridge support, was instrumented and its settlements measured since its construction (Mendoza and Orozco 2002). The construction started on August 9, 1995 and finished on August 3, 1996. From the settlement data the author found adequate to consider as the origin of time October 28, 1995, that is, 80 days after the start of the construction. Fig. 6 shows the measured settlements just after the conclusion of the foundation as well as the theoretical curve applying (4). It was found S_T = 96 cm, δ = 0.66 and t^* = 2440 days = 6.68 years. The last experimental point in Fig. 6 corresponds to February 2004. (Personal communication by Mendoza).

5 CONCLUSIONS

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 corresponds 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 and to a friction-piled box foundation in Mexico City clay.

REFERENCES

Akai, K. 2000. Insidious settlement of superreclaimed offshores seabed. *International Symposium on Coastal Geotechnical Engineering in Practice*, Yokohama, 1:243-248.

Juárez-Badillo, E. 1969. Pore pressure and compressibility theory for saturated clays. *Specialty session No. 12 on advances in consolidation theories for clays. Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico*. University of Waterloo, Canada, pp. 49-116.

Juárez-Badillo, E. 1985 a. General time volume change equation for soils. *XI International Conference on Soil Mechanics and Foundation Engineering*, San Francisco, Vol. 1:519-530.

Juárez-Badillo E. 1985 b. General volumetric constitutive equation for geomaterials. Special volume on Constitutive Laws of Soils. *XI International Conference on Soil Mechanics and Foundation Engineering*, San Francisco. Japanese Society for Soil Mechanics and Foundation Engineering, Tokyo, pp. 131-135.

Juárez-Badillo, E. 1988. Postsurcharge secondary compression equation for clays. *Canadian Geotechnical Journal,* 25:594-599.

Juárez-Badillo, E. 1991. Thirty years of secondary consolidation in sensitive marine clay: Discussion. *Canadian Geotechnical Journal* 28:466-467.

Juárez-Badillo, E. 1997 a. General equations to describe the mechanical behaviour of granular soils. *XIV International Conference on Soil Mechanics and Foundation Engineering*, Hamburg, Vol. 1:133-138.

Juárez-Badillo, E. 1997 b. Case histories illustrate the importance of secondary-type consolidation settlements in the Fraser River delta: Discussion. *Canadian Geotechnical Journal* 34:1007-1008.

Juárez-Badillo, E. 1999 a. Secondary compression of peat with or without surcharging: Discussion. *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE 125 (2):162-164.

Juárez-Badillo, E. 1999 b. General equations to describe the mechanical behaviour of concrete. *Fourth International Conference on Constitutive Laws for Engineering Materials*, Rensselaer Polytechnic Institute, Troy, New York, pp. 403-408.

Juárez-Badillo, E. 1999 c. Static liquefaction of very loose sands: Discussion. *Canadian Geotechnical Journal* 36:967-973.

Juárez-Badillo, E. 2000. General equations to describe the mechanical behaviour of rocks. *Year 2000 Geotechnics*, Asian Institute of Technology, Bangkok, Thailand, pp. 39-52.

Juárez-Badillo, E. 2001. General relaxation equations for soils. *XI International Conference on Soil Mechanics and Geotechnical Engineering*, Istanbul, Vol. 1:141-144.

Mendoza M. J. and Orozco M. 2002. Performance of a friction-piled box foundation in Mexico City clay. *International Workshop ISSMGE, Technical Committee TC 36 Foundation Engineering in Difficult Soft Soil Conditions*, Mexico City.

Tsuchida, T. 2000. Mechanical properties of Pleistocene clay and evaluation of structure due to ageing. *Special Lecture, International Symposium on Coastal Geotechnical Engineering*, IS-Yokohama 2000:39-79.