Evaluation of differential settlements in the airport

L'évaluation des tassements différentiels dans les aéroports

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SYNOPSIS The evaluation of the differential settlements is an important problem in the Offshore Development Project of Tokyo International Airport (TIA), which is being constructed on a soft marine clay. This report outlines a numerical method to evaluate differential settlements, the case study at TIA and its application to the design of the airport pavement.

INTRODUCTION

Japanese Ministry of Transport is carrying out the Offshore Development Project of Tokyo International Airport (TIA) in three stages as shown Fig.1. When the project is completed in 1993, the area of the airport will amount to nearly 1,100 hectares and the airport capacity will be increased by 1.5 times. It is a very important work in TIA project to stabilize its ground,for the site is reclaimed by dredged slurry on a weak alluvial clay. Although several soil improvement methods have been carried out, the part of the consolidation settlement of the weak clay is predicted to take place after opening the airport. To design the facilities in airports, it is necessary to predict both the total and the differential settlements in the reclaimed area. The present work is an attempt to evaluate the differential settlements in the widely reclaimed land.

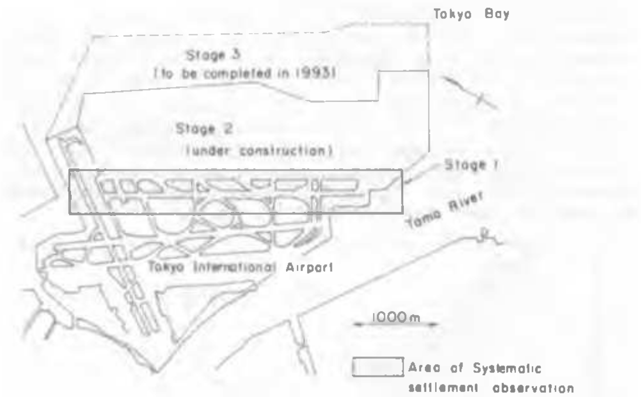


Fig. 1 Outline of the Offshore Development Project of Tokyo International Airport

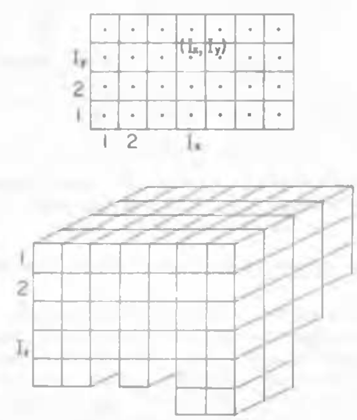


Fig. 2 Probabilistic Modeling of the Ground

PROBABILISTIC MODELING OF THE GROUND

Generally, differential settlements are very complicated phenomenon. In this study the differential consolidation settlement due to the variabilities of soil properties is considered. Soil parameters governing consolidation are compressibility index C_c, thickness of the layer H, coefficient of consolidation c_v, consolidation yield stress p_c, and the initial void ratio. The statistic study showed that these parameters can be described by the normal distribution or the log-normal distribution (Okumura and Tsuchida,1983). Using the probabilistic model of soil properties, Monte-Carlo simulation program FUTO88 was developed to evaluate the differential consolidation settlements in the widely reclaimed land.

In this simulation, the ground is modeled to be the group of the small soil blocks as shown in Fig.2. The distributions of the surface settlements are obtained by calculating the settlements of the blocks by Terzaghi's consolidation theory and adding them. In each trial the soil properties of each soil block is assigned randomly according to its probabilistic distribution model. To evaluate the differential settlements with FUTO88, the auto-correlation characteristic of soil properties and the distribution of the settlements are very important. When the size of the block in Fig.2 is small, the soil properties in the block are not probabilisticly independent and the settlement of the center of the block can not be considered to take place one-dimensionally.

AUTO-CORRELATION CHARACTERISTICS OF SOIL PROPERTIES

Fig.3 shows an example of the auto-correlation of the residual settlements with the horizontal distance. The data of Fig.3 were obtained in Ohi Wharf of Tokyo Port, where the extensive observation of the residual settlements in the reclaimed area had been carried out for 6 years. As shown in Fig.3 the coefficient of auto-correlation gradually decreases with the distances. If τ is modeled by the following form,

$$\tau = \exp(-l/b) \qquad (1)$$

the correlation distance b ranges from 50m to 200m. Other three case studies of the auto-correlation of settlements also showed that the horizontal correlation distance ranges from 50m to 200m (Tsuchida and Ono,1988). In FUTO88 the soil properties of each soil block have the auto-correlation given by Eq.(1) in the horizontal direction. According to Okumura and Tsuchida, the correlation distance of soil properties in the vertical direction ranges from 2 to 3 m. In FUTO88, for the vertical size of the soil blocks is about 3m, the auto-correlation in the vertical direction was not considered. To assign soil parameters to the blocks randomly with the horizontal auto-correlation, the numerical technique introduced by Hoshino and Ishii(1986) is used.

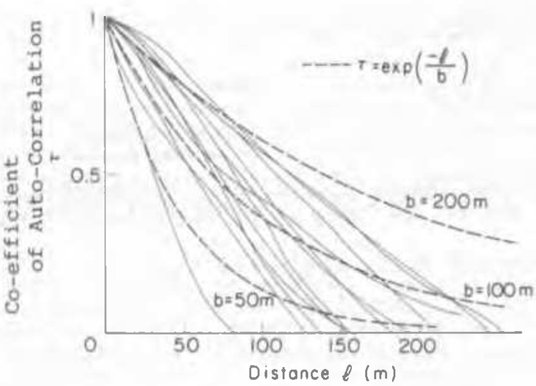


Fig. 3 Auto-correlation of the settlements (Ohi Wharf of Tokyo Port)

EFFECT OF THE DISTRIBUTIONS OF THE SETTLEMENTS

When the horizontal size of the block in Fig.2 is small, the settlement does not take place one-dimensionally and the distributions of the settlements between blocks must be taken into consideration. In FUTO88 the influential coefficient of settlement I_i is newly introduced. In Fig.4 I_i is defined by the following form,

$$I_i(B,h) = s_i/s^* \qquad (2)$$

where B and h are the width and the depth of the soil block respectively, s^* is the settlement of the block calculated with one-dimensional consolidation theory, s_i is the distributed settlement at the surface and i shows the horizontal distance between the soil block and the surface point. Assuming that the ground is elastic and axi-symmetric, I_i shown in Fig.4 was obtained by the finite element analysis. The surface settlement s at the point (I_x,I_y) in Fig.2 is calculated by the following equation,

$$s = \sum_{i_x=I_x-2}^{I_x+2} \sum_{i_y=I_y-2}^{I_y+2} \sum_{i_z=1}^{N_z} I_i\, s(i_x,i_y,i_z) \qquad (3)$$

where N_z is number of the layer.

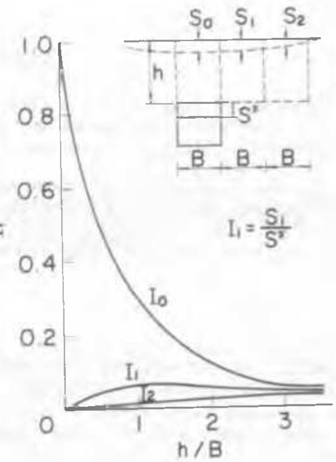


Fig. 4 Influential Coefficient of Settlement

CASE STUDY OF TOKYO INTERNATIONAL AIRPORT

The first stage of the Offshore Development Project of TIA has completed in July 1988. To evaluate the differential settlements in the area, extensive observations of settlements have been carried out in the darkened zone in Fig.1. The geological profile along the axis of the runway is illustrated in Fig.5. It is seen that below the surface soil a thick reclaimed slurry and the soft alluvial clay are distributed. To accelerate the consolidation settlement, paper drains and sand drains were installed in the reclaimed slurry. The physical properties of the reclaimed slurry and the soft clay are exemplified in Fig.6.

Two types of field observations were carried out. In the Wide Area Observation (WAO) the whole reclaimed area were covered by 102 settlement gauges and the distances between the gauges ranged from 30m to 100m. In the Small Area Observation (SAO) the 400 settlement plates were installed within a special area of 40m square.

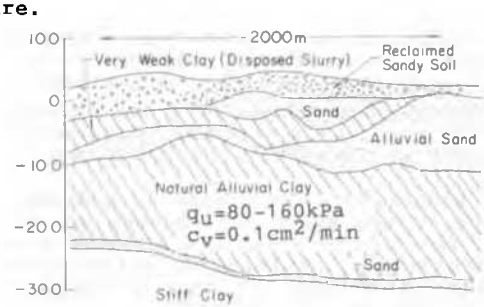


Fig. 5 Geological Profile of Tokyo International Airport

Indexes to represent the differential settlement were defined as shown Fig.7 and the statistic analysis of observed settlements in WAO and SAO were carried out. The indexes are summarized in Table 1. As shown in Table 1, in WAO, the width of differential settlement l ranges from 100m to 400m with the average 160m. In SAO, although the uniform inclination was observed, the differential settlements with the small width were not observed. This means that the differential settlements in the reclaimed land take place with the large width.

The numerical simulations with FUTO88 program were carried out in WAO and SAO. Table 2 shows the soil parameters used in the simulation, which were obtained by the statistic analysis of laboratory test results. The loading condition was given based on the record of the reclamation on the site. The averages of indexes of differential settlements obtained by the simulation are summarized in Table 3. Fig.8(a)(b) shows the examples of the observed and the calculated settlements along a line both in WAO and in SAO. The calculated settlement in Fig.8 is given as $\mu \pm \sigma$, where μ and σ are the mean and the standard deviation of the settlement, respectively. Fig.8 shows that the calculation with FUTO88 gave the general tendency of the differential settlements in both sites, although there is some discrepancy between the observed and the calculated settlements. Comparing Table 1 and Table 3, the results of the simulation underestimated the indexes of the differential settlements by 20-30%. The reason of the discrepancy may be due to the uncertainty, such as randomness of the loading condition or existence of hidden sand layers, which were not considered in the simulation.

Table 1 Indexes of Differential Settlement (Field Observation)

	WAO	SAO
Maximum D. S. (cm)	22.5	20.0
Average D. S. (cm)	7.4	16.1
Average Width of D. S.(m)	160	-
Average Inclination (%)	0.024	0.08

Table 2 Parameters used in the simulation

	Mean*	V**
C_c	1.9-2.2	0.20
c_v(cm^2/min)	0.8-1.2	0.30***
e_0	2.1-2.3	0.15
p_y(kPa)	4z+67****	0.20
H(m)	15.0-18.0	0.10

*The means are depending on the location.
**Coefficient of Variation
***Log-normal distribution (Other parameters are normal distribution).
****z(m) is the depth.
*****Correlation distance in the horizontal direction is 50m. Wet density is 1.5g/cm^3.

Table 3 Indexes of Differential Settlement (The results of the simulation with FUTO88)

	WAO	SAO
Maximum D. S. (cm)	17.2	11.6
Average D. S. (cm)	9.3	10.9
Average Width of D. S.(m)	104	-
Average Inclination (%)	0.028	0.02

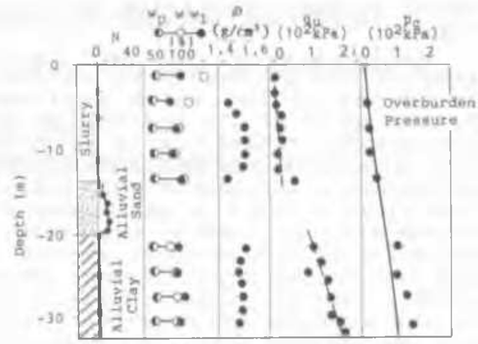
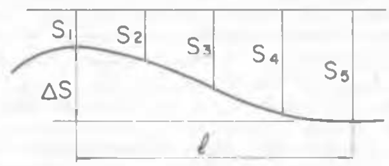


Fig. 6 Physical Properties of Soft Clay in Tokyo International Airport



S1~S5:Settlements
ΔS :Differential Settlement
l :Width of Differential Settlement

Fig. 7 Indexes of Differential Settlement

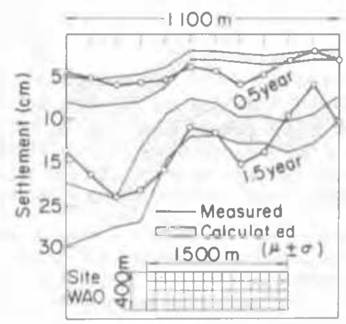


Fig. 8 (a) Measured and Calculated Settlements (Wide Area Observation)

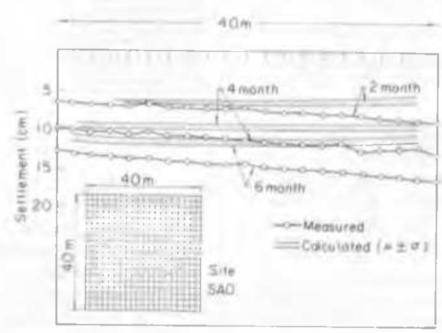


Fig. 8 (b) Measured and Calculated Settlements (Small Area Observation)

APPLICATION OF THE SIMULATION TO AIRPORT PAVEMENT DESIGN

The design of the pavements of aprons and taxiways is one of the major engineering problems in stage 2 of TIA project. With the simulation program FUTO88, it is possible to predict the damages of the pavement due to the future differential settlements with time after opening the airport. Fig.9 is an example of the model ground and the loading condition. The curvature radius of the pavement surface is a good index for its structural damage (Tsuchida and Ono,1988). And each airport facility has a code for its surface inclination. In this example it was assumed that the site is 200m square apron with the asphalt pavement, the critical curvature radius of the asphalt pavement is 1000m and the allowable change of the surface inclination is 0.25%. 50 trials were carried out. With each trial the distributions of settlements were converted to the distribution of the curvature radius R and the surface inclination t. Fig.10 shows the average of R_{min} and t_{max} with time, where R_{min} is the minimum value of R and t_{max} is the maximum value of t in the site. Further the rate of the damaged area, where the curvature radius is less than the critical value or the the surface inclination exceeds the allowable value, were obtained. Fig.11 shows the average of the rate of the damaged area with time after opening the airport. In this example it was predicted that, although the residual settlement was about 40cm, the damages due to the differential settlements would not be seen during first 10 years.

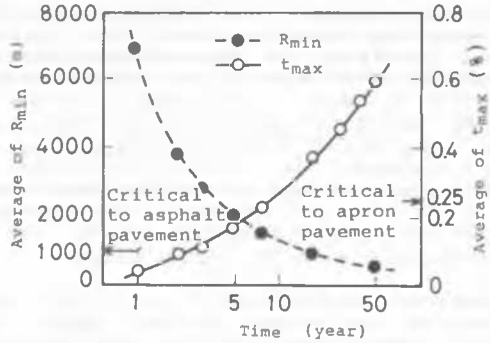


Fig. 10 Average Rmin and tmax with Time (50trials)

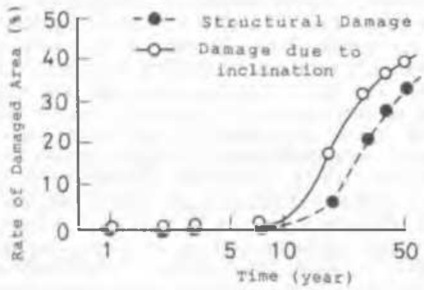


Fig. 11 Average Rate of Damaged Area with Time

CONCLUSIONS

1. A numerical method to evaluate the differential settlement in widely reclaim -ed land was developed.
2. The horizontal correlation distance in reclaimed land ranged from 50m to 200m.
3. The extensive settlements observations were carried out in the Offshore Development Project of Tokyo International Airport. The result of the simulation agreed favorably with the field observation.
4. The damages of airport pavements due to the future differential settlements could be predicted by the present study.

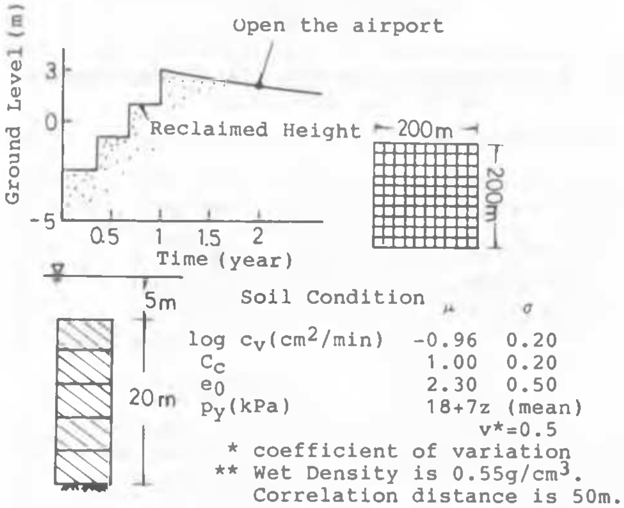


Fig. 9 Model Ground and Loading Condition

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