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Trial of geotechnical asset management for highway embankments constructed on soft clay foundations

Méthode de gestion du patrimoine des talus autoroutiers construits sur du sol argileux

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ABSTRACT

This paper describes a trial of geotechnical asset management for highway embankments placed on very soft clayey grounds at Ebetsu, Hokkaido in Japan. The highway was constructed 30 years ago and is still settling year by year requiring a considerable cost of maintenance. The paper consists of (i) characterization of the ground conditions at the sites, (ii) the class B predictions of the mechanical behaviour of embankments during construction works employing a soil/water coupled finite element code, (iii) predictions of long-term settlement of the embankments based on the information obtained at the stage (ii), (iv) estimates of maintenance cost of the embankments based on the computed long-term settlement and (v) verification of the proposed method of geotechnical asset management by comparing the maintenance cost estimated based on the above stated method and the maintenance cost actually needed in the past 30 years.

RÉSUMÉ

Ce papier décrit une méthode de gestion du patrimoine des talus autoroutiers actuellement appliquée sur toutes les portions de route où la terre est glaiseuse et très molle à Ebetsu, Hokkaido au Japon. Construite il y a 30 ans, l'autoroute continue inexorablement d'année en année à se tasser exigeant une maintenance extrêmement coûteuse. Le papier se compose : (i) caractérisation des conditions géologiques sur les portions concernées, (ii) prédictions de classe B du comportement mécanique des talus pendant les travaux de construction employant une application d'analyse du couplage des éléments finis sol/eau, (iii) prédictions du tassement à long terme des talus en fonction des informations recueillies durant l'étape (ii), (iv) estimations du coût d'entretien qui en découle et (v) vérification de la méthode proposée en comparant le coût d'entretien estimé et le coût réel dépensé durant ces 30 dernières années.

Keywords : geotechnical asset management, highway embankment, soil/water coupled finite element analysis

1 INTRODUCTION

The deterioration of the existing stock in social capital is one of the issues in connection with sustainable development. The main problems are the reservation of financial resources and the relevant budget allocation. The efficient and effective operation, maintenance and updating of the existing stock are undeniably required. In addition, the consideration of environment and the improvement in the service level for users are also required.

In recent years, the existing highway embankments are considered as "Assets" in the road asset management. This is a new approach of the social-capital management which combines economics and business administration in addition to the traditional engineering practice. The aim of this approach is to provide the decision-making method in the operation, maintenance and updating of a stock based on a medium- and long-term point of view. The before-the-event estimate of the maintenance budget in the future, reduction of a life cycle cost and equalization of the budget for each fiscal year are expected to become available by introducing the asset management.

In geotechnical asset management, the short and long-term planning of maintaining, upgrading and operating road assets are drawn up on the basis of performance models of each road facilities. It is indispensable for these performance models to consider the long-term settlement and deformation of highway embankments that may largely influence on the deterioration of highways especially placed on soft foundation.

This paper proposes a procedure of geotechnical asset management of highway embankments on soft clays fully utilizing a soil/water coupled finite element analysis and describes, as a case study, a trial of geotechnical asset management for highway embankments placed on very soft clayey grounds at Ebetsu, Hokkaido in Japan.

2 PROCEDURE OF GEOTECHNICAL ASSET MANAGEMENT

In the course of construction of highway embankments on soft grounds, site investigation are carried out in advance, then observational construction is performed during construction. Obtained information is managed in a database of a collection of laboratory and field data of subsoil, information of design, records of construction works and monitored performance during construction. Based on these data, the soil-water coupled finite element analysis can be conducted as a sort of post-mortem analysis during the on-going embankment construction. This is the Class B prediction according to Lambe (1973). In the Class B prediction, the unknown factors related to 1) constitutive equation, 2) soil parameters and 3) boundary condition etc. can be selected or modified after trial fitting with monitored performance during construction. These calibrations are one of the condition assessments of a highway embankment on soft foundation complementing the uncertainty of ground information at

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the design stage. The authors expect that the analysis may successfully predict the long-term settlement and deformation of the highway embankment during operation by extending the boundary conditions to longer time period if the Class B analysis can successfully simulate the deformation behaviour during construction. Based on this partially complemented prediction, the performance modelling of each road facilities can be reliably carried out.

3 CASE STUDIES

3.1 *Site and subsoil properties*

Hokkaido Expressway between Sapporo IC - Iwamizawa IC is about 32km of the total extension. The construction work started in 1978 and completed in 1983. Natural water content of 550-1200% of the peat bed is distributed over the subsurface for about 27km out of 32km. Analyzed six sites in Hokkaido Expressway are shown in Figure 1.

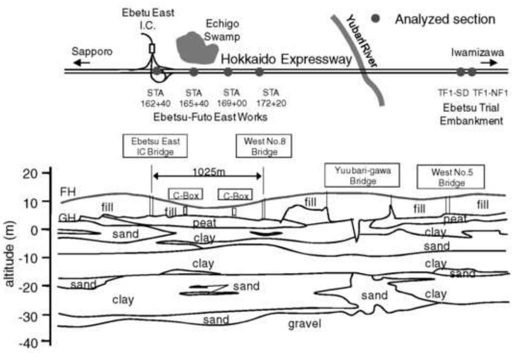


Figure 1. Analyzed sites in Hokkaido Expressway

In this study, six cross sections of STA. 162+40, 165+40, 169+00, 172+20 and two Ebetsu trial embankments are selected as the representative sections. The typical cross section of the embankment is shown in Figure 2. The soft ground is covered by weak alluvium clays of 20-30m thickness. Natural water contents of subsoil in these sections are summarized in Table 1. The sections of STA.162+40, 169+00, 172+20 and Ebetsu trial embankment (SD) were treated by sand drains which were installed in triangular pattern in plan with a 1.5-2.0m centre to centre pitch, 9-12m length and 0.4m diameter. The section of STA.165+40 was treated by sand compaction piles which were installed in square pattern in plan with a 1.4m centre to centre pitch, 10m length and 0.7m diameter. The 1m thick sand mat was placed on the ground surface. Drain pipes of 0.1m diameter were placed from centre to toe of the embankment inside the sand mat.

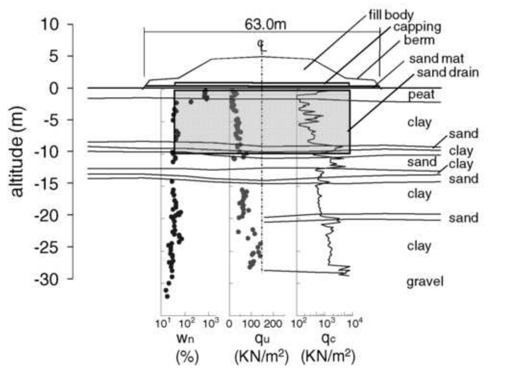


Figure 2. Cross section and subsoil properties of Ebetsu trial embankment

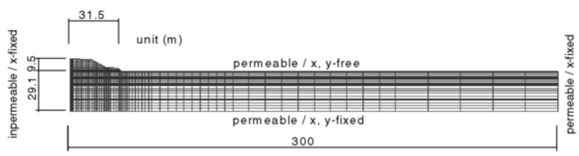
Table 1. Natural water contents of subsoil

(%)

subsoil		Ebetsu-Futo East works				Ebetsu trial embankment	
		162+40	165+40	169+00	172+00	TF-1 SD	TF1-NF1
peat	Ap2-2	200	400 900	950	600	726	726
clay	Am2-2	60	100	100	80	44	44
sand	As2-2	30	30	30	30	30	30
clay	Am2-2	40	40	40	50	41	41
sand	As2-2	-	-	-	-	30	30
clay	Am2-1	-	-	-	-	39	41
sand	As2-1	-	-	-	-	30	25
clay	Am2-1	40	50	50	55	43	43
sand	As2-1	30	30	30	30	30	30
clay	Aml	40	40	40	40	45	45

3.2 *Finite element modelling*

The computer simulations to predict the performance of the trial embankments are carried out employing a soil / water coupled finite element program called DACSAR. This program originally coded by Iizuka and Ohta (1987) and recently revised by Takeyama et al. (2006)[a), b)]. Two dimensional finite element mesh used in this study is shown in Figure 3. Modelling of the embankment is performed by adding fill body elements to the subsoil mesh and loading rate and the thickness of the fill are identical with those in the actual staged construction works.



Furthermore the buoyancy to act under the fill body and drainage resistance of drains are taken into account.

In this analysis, peat layer is modelled by the elasto-plastic model proposed by Sekiguchi and Ohta (1977). Crust can have a significant influence on the result of analysis and is assumed to be linearly elastic. Clay layers are modelled by the elasto-visco-plastic model proposed by Sekiguchi and Ohta (1977). Compacted fill material, sand mat and sand layers are assumed to be a linearly elastic.

Parameters needed in modelling should primarily be determined through the triaxial tests (KoUC/IUC), oedometer tests and permeability tests. However some of these laboratory tests were not performed prior to these construction works. In order to verify the utility of the proposed asset management support method, a determination method of the input parameters utilizing the existing data is thought out. Some empirical correlations between natural water content and various soil properties are found as shown in Table 2.

Table 2. Empirical correlations for local peat and clays

	clay (Am1)	clay(Am2-1)
w_n (%)-Lig (%)	-	-
w_n (%)-w_L (%)	w_L =0.978 w_n+6.85	w_L =0.826 w_n+8.22
w_n (%)-e_i	e_i =2.75 w_n/100	e_i =2.74 w_n/100
w_L (%)-I_p(%)	I_p=0.77(w_L -17)	I_p=0.80(w_L -17)
w_L (%)-C_C	C_C=0.015(w_L -20)	C_C=0.016(w_L -20)
C_C-C_S	C_S= C_C /10	C_S= C_C /10
OCR-σ'_{vi} (kN/m^2)	OCR=4.02-0.594ln(σ'_{vi})	OCR=3.14-0.406ln(σ'_{vi})

	clay(Am2-2)	peat(Ap2-2)
w_n (%)-Lig (%)	-	w_n =10 Lig
w_n (%)-w_L (%)	w_L =0.711 w_n+15.45	-
w_n (%)-e_i	e_i =2.65 w_n/100	e_i = w_n/100 × 1/(0.00237 Lig+0.356)
w_L (%)-I_p(%)	I_p=0.75(w_L -15)	-
w_L (%)-C_C	C_C=0.014(w_L -20)	C_C=0.088Lig
C_C-C_S	C_S= C_C /10	C_S= C_C /10
OCR-σ'_{vi} (kN/m^2)	OCR=4.57-0.633ln(σ'_{vi})	OCR=4.08-1.072ln(σ'_{vi})

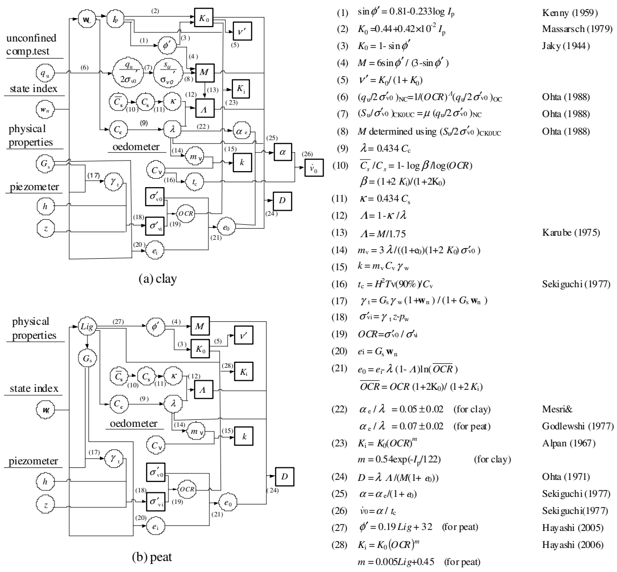
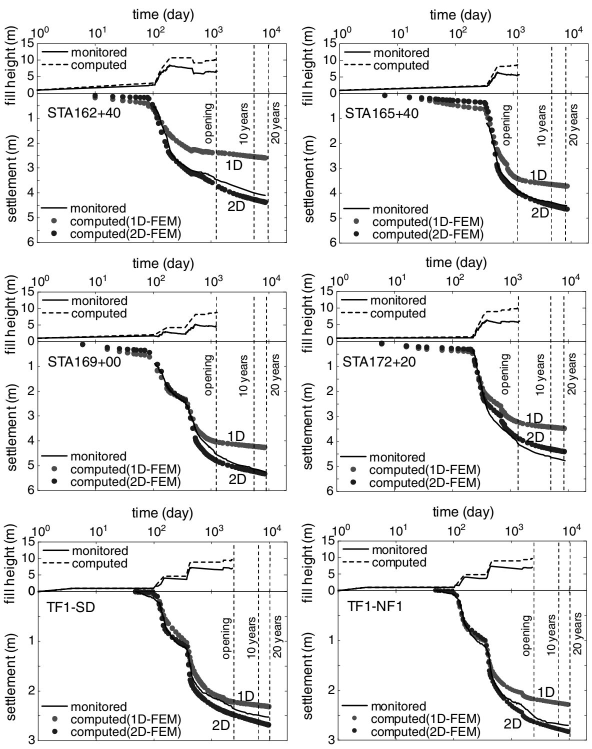


Figure 4. Parameter determination chart for peat and clays

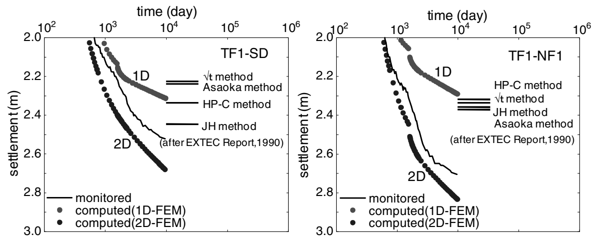
The input parameters used for analysis are firstly identified according to the input parameter determination chart shown in Figure 4 using the correlation of Table 2. The input parameters of sand layer are determined by using correlation between the cone bearing capacity qc and deformation parameters after Lunne and Christophersen (1983). The coefficient of permeability is presumed by the method of Creager (1945) using the 20% particle diameter obtained from site investigation of the Ebetsu trial embankments. The estimated value of permeability coefficient used as the parameter in sand drain area is modified by multiplying the correction factor calculated from the theory by Yoshikuni (1972). Thus estimated permeability used in sand drained area is about 10 times larger than the permeability coefficient obtained from laboratory tests. The sand compaction piles installed at STA165+40 are modelled by modifying the compression and swelling indices depending on replacement ratio of sand compaction piles.



Figures 5. Computed settlement under the centre of embankment by one-dimensional analysis and two-dimensional analysis being compared with the monitored performance

The computed settlement under the centre of embankment by one-dimensional analysis and two-dimensional analysis being compared with the monitored performance are shown in Figs 5. Figs 5 summarize the computed and monitored settlement at the end of earth filling work. It should be noted that the predictability of long-term settlement is largely improved by modifying the permeability of sand layers in such a way that the analyses made during construction period produce the results relatively in good agreement with monitored ones.

The one-dimensional finite element model using the same parameter predicts somewhat less settlement. EXTEC (1990) introduced the final settlement of TF1-SD and NF1 estimated by four different methods (the root t method, the Asaoka method, a hyperbolic curve method, and the JH method). The comparison is summarized in Figs 6, indicating that any of these four approaches predicts long-term settlement less than observed in the same fashion as the one-dimensional finite element model.



Figures 6 Comparison between long-term settlement predictability of soil/water coupled analysis and four other prediction methods

3.3 *Prediction of life-cycle maintenance cost of the embankments based on the computed long-term settlement*

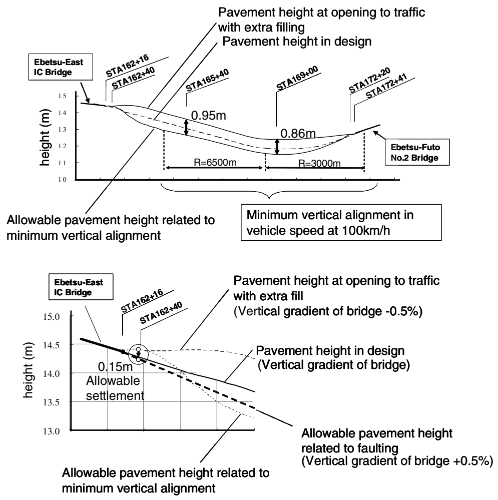
When settlement does not finish during construction and finish after opening to traffic, it is necessary to expect the budget for maintenance and repair of pavement since the differential settlement near the bridges and culvert boxes occurs. Table 3 shows the examples of relationship between performance indicators and required performance levels of the highway embankments on soft grounds. The geotechnical indicators of highway embankments consist of settlement, vertical and lateral displacement. These indicators are not only measurable at the sites but also predictable by the soil / water coupled finite element analysis. The required performance levels are mainly taken from the Regulation of Road Structures in Japan and are to be regarded as the fundamental performance requirements of highway.

In this paper, the life-cycle cost of asphalt overlay based on the settlement computed by 2D-finite element analysis is estimated. Allowable vertical alignment, minimum radius of vertical alignment and bridge approach settlement for the vehicle speed of 100km/h in the performance-related indicators shown in Table 3 are compared with those actually monitored at the sites. Figs 7 show the relationship between geotechnical indicator of settlement and performance related indicators of vertical alignment and bridge approach settlement. As seen in the upper figure of Figs 7, the allowable amounts of settlement at STA165+40 and STA169+00 are 0.95m and 0.86m respectively. As seen in the lower figure of Figs 7, the allowable settlement at STA162+40 is 0.15m. The allowable settlement at STA172+20 is 0.16m although it is not shown in Figs 7.

Table 4 shows the timing of asphalt overlay predicted by the computed settlement in comparison with the actual overlay in the past 20 years. The predicted timing of asphalt overlay

Table 3. Example of relationships between performance indicators and required performance levels of the highway embankments on soft grounds

Geotechnical indicator	Performance-related indicator	Required performance level								
settlement	- vertical alignment	design speed(km/h)	120	100	80	60	50	40	30	20
		gradient (%)	2	3	4	5	6	7	8	9
	-minimum radius of vertical curve	design speed(km/h)	120	100	80	60	50	40	30	20
		crest (m)	11000	6500	3000	1400	800	450	200	100
		sag (m)	4000	3000	2000	1000	700	450	250	100
	- cross slope	1.5% < i < 2.0% *defined separately in the section of curve								
	- bridge approach settlement	gradient of differential settlement < 1/200 (0.5%)								
	- faulting	faulting < 20mm								
	- road width	design speed(km/h)	120	100	80	60	50	40	30	20
		width (m)	3.5	3.5	3.5	3.25	3.0	3.0	2.75	2.75
		*defined by the road classification								
settlement / lateral displacement of embankment toe	- safety factor of slope failure	Fs > 1.1								
lateral displacement of embankment toe	- ground inclination	deformation angle of building structure 3-5 / 1000 rad								
		ground inclination of building structure 6-8 / 1000 rad								
vertical displacement of embankment toe	- settlement	settlement of paddy field < 60mm								



Figures 7. Relationship between geotechnical indicator of settlement and performance related indicators of vertical alignment and bridge approach settlement

agrees relatively well with the actual ones. It should be noted that, in each of 4 sections in Table 4, one special overlay work is counted in addition to the overlay works needed by the excessive settlement. This overlay was needed due to other reason and planned to be made in the 4th year but actually made in the 6th year.

Table 4. Predicted and actual asphalt overlay timing during the past 20 years

Predicted		
STA	Times of overlay	Timing of overlay (year)
162+40	5	1st,3rd,4th,8th,19th
165+40	1	4th
169+00	1	4th
172+20	4	1st,3rd,4th,15th

Actual		
STA	Times of overlay	Timing of overlay (year)
162+40	5	1st,2nd,4th,6th,9th
165+40	1	6th
169+00	1	6th
172+20	6	1st,2nd,3rd,4th,6th,11th

Table 5 shows the predicted and actual life-cycle costs (LCC) of asphalt overlay during the past 20 years. The actual life-cycle cost in Table 5 means the life-cycle cost estimated based on the settlement actually observed at the sites and is not the total amount of money (177,000 thousand yen) actually used in asphalt overlay during the past 20 years. The same unit price of asphalt overlay is used to compare the predicted cost and actual cost on the same basis. The present value method is used in LCC estimate. The standard formula for discounting is: PV = $[1/(1+r)^t]\ A_t$ where, PV = present value at time zero (the base year); r = discount rate; t = time (year); and A = amount of

Table 5. Predicted and actual life-cycle cost of asphalt overlay during the past 20 years

discount rate (%)	predicted LCC (A) (thousand yen)	actual LCC (B) (thousand yen)	(A) / (B)
0.0	140,900	158,900	88.7
1.0	133,829	149,955	89.2
3.0	121,400	133,919	90.7
5.0	110,838	120,023	92.3
7.0	101,711	107,935	94.2
9.0	93,736	97,380	96.3

benefit or cost in year t. The predicted life-cycle costs of asphalt overlay agree well with the actual ones.

4 CONCLUSIONS

Trials of making Class B predictions of the possible performances of highway embankments placed on very soft subsoil evidenced in this paper that the current technique of soil/water coupled finite element analysis is reliable enough to be used in long-term prediction of settlement of highway embankments on soft clay foundation. The life-cycle cost prediction of highway embankment based on the numerical modelling may be found to be applicable and efficient for use in geotechnical asset management. The authors hope that the importance of the geotechnical engineering in asset management will be widely recognized.

REFERENCES

Creager, W. P., Justin, J. D., and Hinds, J. 1945. *Engineering for dams* vol. 3, earth, rock-fill, steel and timber dams, Willy, Newyork, pp.648-649.

EXTEC. 1990. Report of Hokkaido expressway Sappro IC-Iwamizawa IC (in Japanese)

Iizuka, A., and Ohta, H. 1987. A determination procedure of input parameters in elasto-viscoplastic finite element analysis. *Soils & Foundation*, Vol.27, No.3, pp.71-87.

Lambe,TW. 1973 Prediction in Soil Engineering, *Geotechnique* 23, pp.149-202

Lunne, T. and Christophersen, H.P. 1983. Interpretation of cone penetrometer data for offshore sands, *Proc Offshore Technology Conference*, Richardson, Texas, Paper No.4464.

Sekiguchi, H. and Ohta, H. 1977. Induced anisotropy and time dependency in clays, Constitutive Equation of Soils, *Proc. 9th International Conference on Soil Mechanics and Foundation Engineering*, Specialty Session 9, pp.305-315.

Takeyama, T., Ohta, H., Iizuka, A., Pipatpongsa, T. and Ohno, S. 2006[a]. Method to cope with the singular point of yield surface in Sekiguchi-Ohta Model, *Proc.3rd Geo-kanto*, pp.313-317. (in Japanese)

Takeyama, T., Iizuka, A. and Ohta, H. 2006[b]. Spatial descritization of water using approximation by linear function, *Proc. of 41th Japanese National Conference on Geotechnical Engineering*, pp.321-322 (in Japanese)

Yoshikuni.H. 1979. *Design and construction of vertical drain*, Gihoudou. (in Japanese)