Estimate of the salt contamination sprayed on the highway pavement during the snowy winter

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ABSTRACT

In Akita region along the northwest coast of Japan, about fifty tons of salt per kilometre of the highway is used to prevent the snow on the road surface from freezing every year. Reported in this paper is the estimate of the salt contamination in paddy fields adjacent to Akita Expressway. The speed of the travelling diffusion front of the possible saline ground water was estimated as low as 2 mm/year. In the paper, we also review the current operation of Akita Expressway in terms of snow removal and freeze prevention during the winter season.

Keywords: finite element analysis, highway embankment, salt contamination

1. INTRODUCTION

Reported is the estimate of the salt contamination in paddy fields adjacent to Akita Expressway that runs from north to south along the northwest coast of Japan. The region is characterized by the heavy snow-fall brought by the cold moist wind from the north-west travelling across the sea. The highway embankments located at Soto-Asahikawa were constructed over five years and opened to the traffic in November, 1997. The expressway ran parallel to the edge of a young Holocene plain sit on a soft clay deposit overlaying the bed rocks sloping down from the east (hill side) toward the west (paddy field side). At the stage of planning, there remained the possibilities that (i) the sections of the highway embankment could slide laterally on the sloping bed rock and (ii) the underground water flowing from the hill side to the plain through the Holocene sediments might carry the saline produced by spraying the salt and could contaminate the paddy fields. In Akita region, about 52 tons of salt per kilometre of the highway is used to prevent the snow on the road surface from freezing every winter. This amount of salt is much more if compared with 5-20 tons per kilometre in Germany, 5-10 tons per kilometre in Austria and Belgium. It was 36 tons per kilometre when the spike tires were used in Japan, but it increased to 52 after the usage of spike tires was forbidden. A series of analysis was carried out to simulate the performance of the embankments under construction. Displacement and deformation of the fill body and the soft foundation were monitored thoroughly throughout the construction period.

2 CONSTITUTIVE MODEL AND SOFTWARE USED

In this paper, non-commercial software called DACSAR (Deformation Analysis Considering Stress Anisotropy and Reorientation) was used to simulate the performance of the embankments monitored during construction. Soil-water coupled finite element code DACSAR originally coded by Iizuka and Ohta (1987) and improved by Takeyama, Iizuka and Ohta (2006) is available to any users free of charge. In addition to the theoretical frame-work of DACSAR code, they presented a determination procedure of the input parameters by showing that all the parameters are specifiable using the results available from in-situ and laboratory tests commonly carried out in the geotechnical engineering practice. They improved later in 2006 the numerical method handling the gradient of the pore water head governing the pore water migration. Mestat (2001) recognized DACSAR as the second most popular FE code.

An elasto-viscoplastic constitutive model developed by Sekiguchi and Ohta (1977) is incorporated to DACSAR. The Sekiguchi-Ohta model was developed based on the dilatancy coefficient defined by Shibata (1963). A special treatment was proposed by Takeyama, Pipatpongsa, Iizuka and Ohta (2013) making it possible to derive incremental stress-strain relations associated with a stress point at the singular point of the yield surface. They also defined the stress space in which the metastability in a sense defined by Roscoe, Schofield and Thurairajah (1963) is generated. Duncan (1994) recognized the Sekiguchi-Ohta model as the second

most popular constitutive model.

3 ANALYSED CROSS SECTION

Fig. 1 shows the plan of the site where we have three sections BC11, BC21 and BC31 of the road embankment sitting on a soft Holocene sediments overlaying the bed rocks sloping down from the east (hill side) toward the west (paddy field side). In this paper, only the section BC11 is analysed.

As shown in Fig. 2, the highway embankments consisting of a sand mat layer and the fill body are placed on a relatively hard surface crust (0.5m thick) underlain by extremely soft and compressive peat layer (4.5m thick) that sits on two layers of clay at BC11. Clay 1 (10.0m thick) is the first layer of clay characterized by very high water contents and high compressibility. Clay 2 beneath Clay 1 is a sort of normal soft clay usually encountered in geotechnical engineering practice. Aiming at acceleration of consolidation process of the soft foundations loaded by placement of the embankments, sand drains were in-stalled through the layers of peat and Clay 1 under the main fill bodies as indicated in Fig. 2.

Fig. 3 shows the summary of soil properties of undisturbed samples of soft materials obtained at the site. The water contents in the peat layer are extremely high and the unit weight of the peat is in a range just a little larger than the unit weight of water indicating that the peat is a material closer to the water rather than soil. This implies that the fill body would have excessively settled during the progress of embanking work. Clay 1 is lightly overconsolidated clay with medium plasticity. This overconsolidation seems to be of diagenetic origin. Both of Clay 1 and 2 would have become more deformable when the fill bodies were placed because the load induced by placement of the fills is obviously greater than the preconsolidation pressure.

4 MATERIAL PARAMETERS NEEDED IN THE SIMULATION

Fig. 4 is a chart for estimating material parameters of peat and clay based on the data such as those

Fig. 1. Plan of the site of sections of highway embankment.

Fig. 2. Soft foundations overlaying the sloping bed rocks.

Fig. 3. Soil properties at analysis section.

Fig. 4. Chart for estimating material parameters of peat and clay.

summarized in Fig. 3. By accumulating the experiences of employing the Sekiguchi-Ohta model incorporated in DACSAR code in analysing the performance of road embankments placed on soft foundations, Ishigaki, Omoto, Takeyama, Pipatpongsa, Iizuka and Ohta (2007) modified the parameter estimating procedure proposed by Iizuka and Ohta (1987) and proposed a chart shown in Fig. 4. The equations are listed on the right side of Fig. 4. Some of the equations are theoretically derived and others are empirically established. The soil properties such as those plotted in Fig. 3 are seen on the far left side of Fig. 4 being placed in double circles. Table 1 summarizes thus obtained material parameters of the fill body, sand mat, surface crust which are modelled as elastic materials and of the

Table 1. Material parameters used in the deformation analysis.

Layer	γ kN/m ³	E MPa	ν	k m/day	D	Λ	M
Fill	16.3	20.7	0.33	3.5×10^{-4}			
Sand mat	17.4	9.8	0.33	5.6×10^0			
Crust	15.2	10.0	0.33	5.5×10^{-4}			
Peat	12.3		0.28	5.5×10^{-4}	0.075	0.85	2.90
Clay1	14.7		0.41	4.0×10^{-4}	0.103	0.88	0.91
Clay2	16.3		0.38	1.0×10^{-4}	0.070	0.87	1.00

Layer	K_0	K_i	α	$\dot{\nu}_0$	λ	e_0	λ_k
Peat	0.38	0.84	0.01780	1.4×10^{-7}	1.97	6.74	0.95
Clay1	0.70	0.87	0.00534	2.1×10^{-7}	0.33	2.09	0.31
Clay2	0.62	0.78	0.00410	7.8×10^{-8}	0.19	1.32	0.14

peat layer, Clay 1, Clay 2 which are assumed as elasto-viscoplastic materials for the section BC11.

5 PRELIMINARY ESTIMATE OF GROUND WATER FLOW

The simulation of settlement and lateral displacement of the embankments and the soft foundations and seepage flows after the completion of consolidation at BC11 are made in three steps two of which will be introduced later. First step is the preliminary estimate of possible ground water flow from the hill side to the paddy field side. Permeability k of each of the materials forming the soft foundation is listed in Table 1 and permeability of the bed rock is assumed as 8.64×10^{-4} m/day. The ground surface is a drained boundary while the other boundaries are assumed as undrained boundaries. The boundary condition on the right end of the analysed domain is specified by the total water head hydrostatically corresponding to the height of the hill indicated at the right end of Fig. 5. Fig. 5 shows contour of the total water head of the ground water flowing from the hill side (right side of the figures) to the paddy fields. The total water head at the boundary between the bed rock and Holocene sediments is less than 1m indicating that the ground water flows slowly from the hill side to the paddy fields under conditions of steady state.

Fig. 5. Contours of total water head.

Fig. 6. Mesh and boundary conditions for deformation analysis.

6 DEFORMATION ANALYSES OF THE FOUNDATIONS LOADED BY PLACEMENT OF EMBANKMENTS

As mentioned in the previous section, the simulation of settlement and lateral displacement of the embankments and the soft foundations and seepage flows after the completion of consolidation are made in three steps. In this section, introduced is the second step in which the deformation of the fill body and the foundation loaded by placement of the each embankment is analysed.

Fig. 6 is the mesh and boundary conditions for deformation analysis. The boundaries between the Holocene sediments and bed rocks are assumed as undrained boundaries in the deformation analysis. They are specified by abc in Fig. 6. In the seepage analysis which will be introduced in the following section, the boundaries bc are treated as drained boundaries allowing the ground water migrating from the bed rocks on the hill sides into the Holocene sediments. Construction of the fill body is simulated in the analysis by placing one embankment layer on top of the sand mat and another embankment layer on top of the previous embankment layer and so on in a sequential manner simulating the loading process actually performed during the construction period.

Fig. 7 shows the loading process of the embankment (fill thickness plotted against elapsed time) and the associated settlement monitored by the settlement gauges placed at the ground surface and lateral displacement of the soft foundations being compared with the values calculated in the deformation analysis. Monitored and simulated values are in acceptably good agreement implying that the computer simulation reasonably well simulates what happened at the sites during the period of construction works. It should be noted that permeability of the soft Holocene sediments has greatly decreased due to the decrease in the void ratio caused by the densification of the materials

Fig. 7. Monitored and simulated settlement and lateral displacement.

consolidated by placing the fill bodies. This decrease in permeability of the Holocene sediments is expected to work as a sort of barrier to prevent the quick flow of the ground water possibly contaminated by spraying NaCl during the winter seasons.

7 GROUND WATER FLOWS IN THE STADY STATE

Fig. 8 shows the result of the seepage flow analysis indicating that the velocity of the ground water flow on the paddy field side of the embankments is extremely low, i.e. less than 2 mm/year. The Holocene sediments are assumed in this third step of analyses as elastic materials with high rigidity. In this analysis, the total water head shown in Fig. 5 (0.8m) is used as the boundary condition on the boundary specified by bc in Fig. 6.

8 CONCLUSION REMARKS

In Akita region introduced in this paper, we have snowfall of 3-7 m/winter. Total length of 91.5 km of highway is under the control of Akita Operation Office, East Nippon Expressway Company. Latest records of operations of snow removal and freeze prevention indicate that we had 40 times/km of operation at sites spending 111 hours/km using 32 special vehicles and 5,000 man day in a winter season. One of the major winter activities is spraying of salt which could trigger the saline contamination of the paddy fields adjacent to Akita Expressway.

Through the analyses introduced in the previous sections, we found that the simulation describes what happened during the construction reasonably well, as the simulated behaviour of the embankments was practically identical to the monitored performance. According to the simulation, the soft Holocene sediments underneath the embankments were compressed by the embankment loads and became much less permeable due to consolidation resulting in the velocity of seepage flow extremely low. The speed of the travelling diffusion front of the possible saline ground water was estimated as low as 2 mm/year assuming the maximum possible water head difference of 1 m. Our simulation guaranteed that there would be practically no soil contamination in the neighboring paddy fields.

Fig. 8. Velocity of the ground water flow at the steady state.

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