Panel discussion: Geotechnical criteria for selecting mechanized tunnel system and DMM for tunneling

Débat de spécialistes: Critères géotechniques pour le choix d'un système de construction de tunnel mécanisé et de la méthode de 'Deep Mixing'

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ABSTRACT: This paper describes the following two issues suggested by the theme lecturer on Underground Works in Urban Environment ; 1. Geotechnical Criteria for selecting mechanized tunneling system in Japan. 2. Recent experience of using Deep Mixing Method for tunneling.

1 GEOTECHNICAL CRITERIA

Geotechnical Criteria for selecting mechanized tunneling system in Japan are as follows. Figure 1 shows the general flow of how to select the mechanized tunnel system, considering various factors such as location, environmental conditions, more importantly, design criterion, length and diameter of tunnel, ground condition, soil types and so forth. Construction period and required are also important factors to be considered. It is clear from the flow that it is absolutely necessity to have experienced and integrated engineering judgment to arrive at the appropriate, yet economical tunneling system for a given project.

Some years ago, Japan Society of Civil Engineers (1996) made a questionnaire survey on what type of shield machines has been used in actual construction projects, over the total length of 800km tunnel construction. The result is summarized in Fig 2. It became evident from the survey that closed face machines, such as slurry shield, earth pressure balanced shield are predominantly used. Among which, the earth pressure balanced shield with additives are the most frequently adopted, in particular for sandy soil and gravel layers.

One of main geotechnical factors in selecting the machine is soil type: clay or sand. To distinguish between soft alluvial clay and stiffer pleistocene clay is also necessary in view of soil strength and water content. Grading information is another important factor, such as fine content, sand content, gravel content. Ground water pressure also forms an important factor from the view point of water tightness of the tunnel system, specially at a discharged gate, in particular for cases of sandy or gravel layers.

Figure 3 is a selection chart according to geotechnical condition, given in the Standard Specification for Tunnels published by Japan Society of Civil Engineers (1996), in which the types of machine are classified in terms of soil type and SPT blow count. For example, if you have an alluvial soft clay with SPT-N say 2, you could select either earth pressure balanced shield or slurry shield. But if you have a stiffer clay, additives are often needed to maintain flowability in a working chamber of shield because of small water content of the stiff clay. Additives are also needed for sandy soil to keep the face stability and flowability of the excavated soil. When you have gravel layers, slurry shield may not be the best choice, because of possible clogging of the muck transportation pipes and also because of difficulty in obtaining sufficient face stability. We also have to remember that slurry shield tunnel system has treatment facilities which require additional cast and space. In these points in mind, it is said that the earth pressure balanced shield with additives has wider applications.

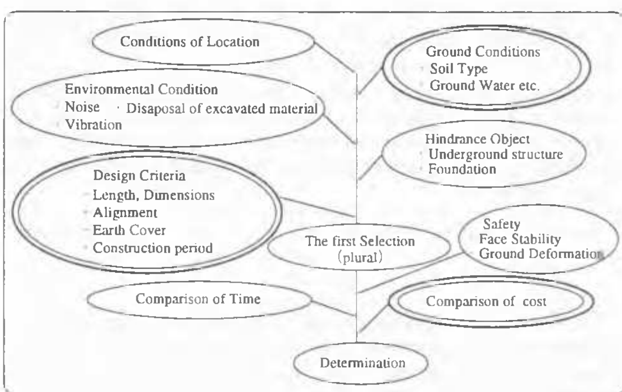


Figure 1. General flow of selecting mechanized tunnel system

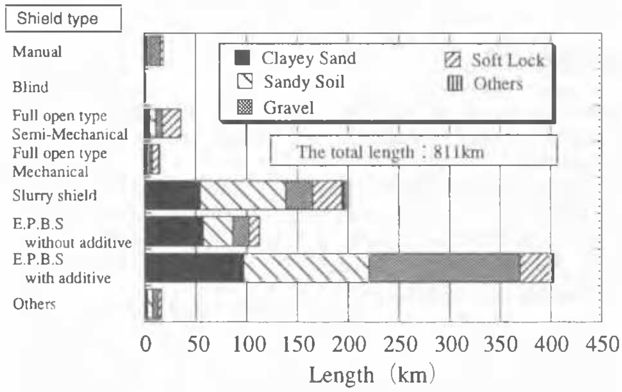


Figure 2. Type of machine used in Japan

Soil Layer \ Shield Type			Closed-type: Earth pressure balanced shield		Slurry Shield
Soil Type		SPT. N	Without Additives	With Additives	
Alluvial Cohesive Soil	Silt · Clay	0 ~ 2	○	○	○
	Sandy Silt · Sandy Clay	0 ~ 5	○	○	○
		5 ~ 10	○	○	○
Pleistocene Cohesive Soil	Loam · Clay	10 ~ 20	▲	○	○
	Sandy Loam · Sandy Clay	15 ~ 25	▲	○	○
		over 25	▲	○	○
Sandy Soil	Sand with Silty Clay	10 ~ 15	○	○	○
	Loose Sandy Soil	10 ~ 30	▲	○	○
	Consolidated Sandy Sand	over 30	▲	○	○
Gravel with Boulders	Loose Gravel	10 ~ 40	▲	○	○
	Consolidated Gravel	over 40	▲	○	○
	Gravel with Boulders	–	▲	○	▲
	Boulder Gravel · Boulders	–	▲	▲	▲

Figure 3. Geotechnical selection chart for tunnel system

2 ADDITIVES

There are basically four types of additives currently been used in Japan: clay minerals such as Bentonite, interfacial action agent, typically foaming agent, polymer types such as CMC and high water absorption resin. Among which most frequently used additives is CMC, which is a kind of viscose increasing agent, followed by other three types. But there is an increasing trend of using foaming agent, partly because the excavated soil with Bentonite sometimes has to be treated as an industrial waste and the overall plant required is relatively large compared to that of foaming agent. Past experiences show that we need more than 30% fine content to have smooth operation. There is an empirical equation of how much additives are required, recommended by Association of Earth Pressure Balanced Shield with Additive Method (1989) as

Concentration(D)

$$= a \times (30 - P_{0.074}) \times \alpha + (40 - P_{0.25}) \times \beta + (60 - P_{2.0}) \times \gamma$$

in which the concentration D. is defined as

$$\text{Concentration (D)} = \frac{\text{Weight of the additive}}{\text{Weight of the water}} \times 100 \ (\%)$$

$P_{0.074}$: 0.074 mm Percentage passing, $P_{0.074}$ = 30 for over 30%
$P_{0.25}$: 0.25 mm Percentage passing, $P_{0.25}$ = 40 for over 40%
$P_{2.0}$: 2.0 mm Percentage passing, $P_{2.0}$ = 60 for over 60%
α : 2.0, β : 0.5, γ : 0.2

a : A coefficient according to Uniformity coefficient (Uc)

a=1.0 Uc≧4
a=1.1 4>Uc≧3
a=1.2 3>Uc>1

Japan has more than 10 years experience of using foaming agent. Based on accumulated experiences, Foam Shield Method Association (1992) comes up with the criterion for required mixing ratio(Q) which is the ratio of volume of foam to the volume of excavated soil. Foam mixture ratio is again expressed by the function of Uc and the same grading characteristics as

Foam Mixing Ratio (Q)

$$= \frac{a}{2} \{ (60 - 4 \times X^{0.8}) + (80 - 3.3 \times Y^{0.8}) + (90 - 2.7 \times Z^{0.8}) \} \ (\%)$$

X : 0.074 mm Percentage passing, $4 \times X^{0.8}$ = 60 for over 60%
Y : 0.25 mm Percentage passing, $3.3 \times Y^{0.8}$ = 80 for over 80%
Z : 2.0 mm Percentage passing, $2.7 \times Z^{0.8}$ = 90 for over 90%

a : A coefficient according to Uniformity coefficient (Uc)

a=1.0 Uc ≧ 15
a=1.2 15 > Uc ≧ 4
a=1.6 4 > Uc

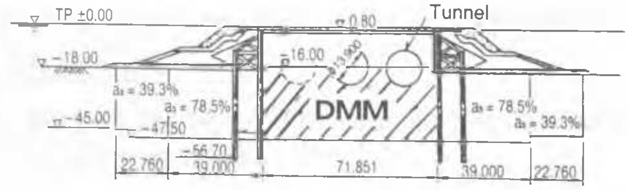
Usually these additives are used in combination in order to select the most suitable conditions for a particular soil being excavated. Thus in addition to manufacturer's specifications, a set of trial mixing tests with the soil is necessary prior to the application.

3 SOIL IMPROVEMENT

There are a wide variety of possible soil improvement methods for tunneling, in which jet grouting method with chemical grouting is frequently used in Japan. But we do have a recent case where Deep Mixing Method (DMM) has been used for tunneling.

In the Trans Tokyo Bay Highway Project which consists of 10km tunnel section and 5km Bridge Section, DMM was applied at Ukishima Access where we have a 30m thick soft alluvial deposit. Slurry shield machine used has a diameter of slightly over 14m.

Figure 4 shows the illustration of improved zone by DMM with 70m wide 30m deep and 700m long. Some design considerations were given to determine the strength and stiffness of the clay improved by DMM, such as sufficient uplift resistance against buoyancy force acting on the tunnel and sufficient stiffness against the embankment loading and also the durability of the shield machine for such as large and long tunnel.



in meters

Figure 4. Improved zone by DMM

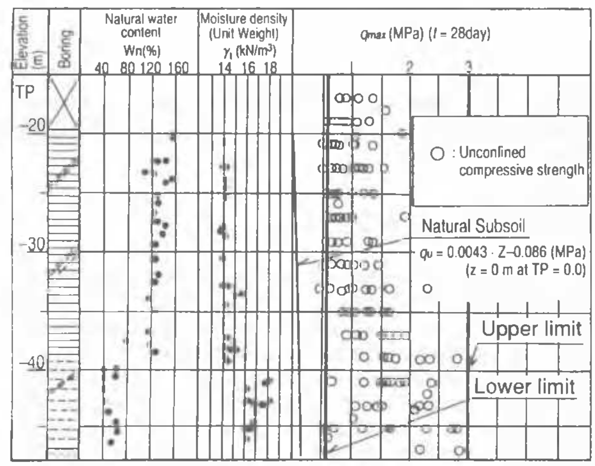


Figure 5. Data of soil strength after improvement

Figure 5 shows some results of soil strength before and after improvement (Japan Society of Civil Engineers, 1996). The soil strength measured scatters within the two limits; the lower limit governed by stability and settlement, the upper limit governed by wear of the cutter.

4 SUMMARY

(1) There exists a standard specification for tunnel, by which the primary selection is carried out. Soil type, grading information and water pressure together with the cost required for treatment facilities and overall plants are crucial factors for the final selection of the machine.

(2) Jet grouting is usually used for soil improvement. A care record of using Deep Mixing Method for tunneling was presented.

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