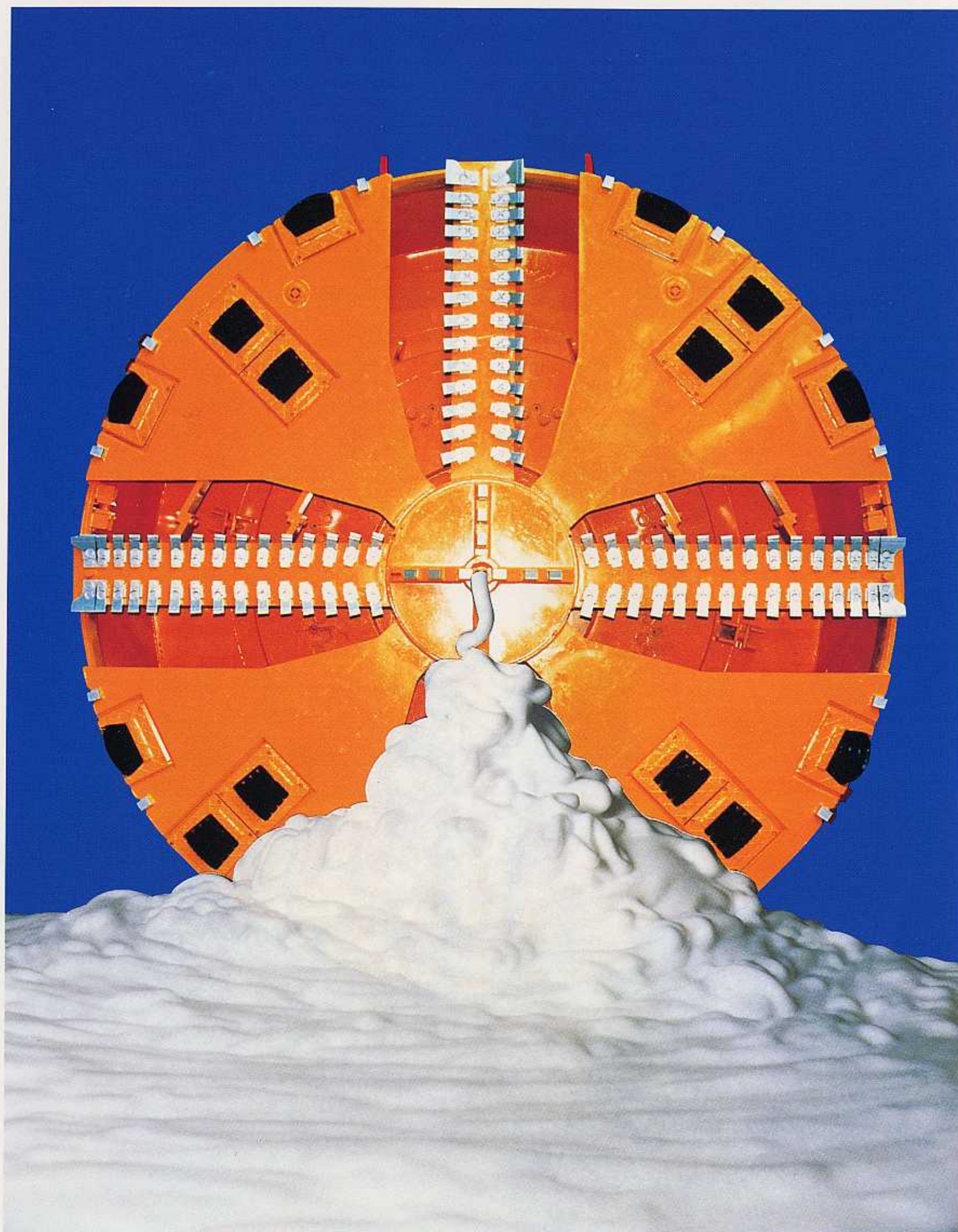

Rheological Foam Shield Tunneling Method



THE RHEOLOGICAL FOAM SHIELD TUNNELING METHOD ASSOCIATION

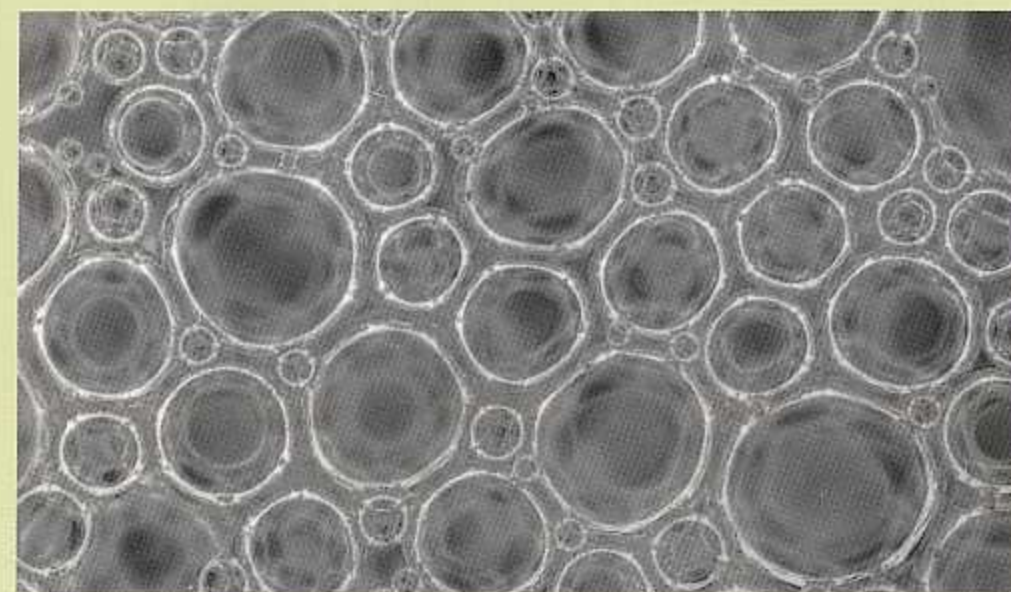
Foam Injection - An Effective Way to Control Various Ground Conditions



In conventional Earth Pressure Balance shield tunneling, the ground at the excavation face is stabilized through the injection of slurry into the chamber and/or at the excavation face. However, this method has a serious drawback: the consistency of the excavated earth is mud-like, and is therefore difficult to transport and process. In addition, large and costly equipment is required for the preparation and injection of slurry.

The innovative Rheological Foam Shield Tunneling Method was created to overcome the problems associated with Earth Pressure Balance shield tunneling. Its versatility makes it ideal for all types of soil types, ranging from gravel to clay strata.

Tunnel excavation with the Rheological Foam Shield Tunneling Method proceeds by the injection at the excavation face and/or into the chamber of a foam produced from a special foaming solution. Injection of the finely-dispersed foam, which has a shaving cream-like consistency, serves to improve the fluidity and water-sealing characteristics of the excavated earth, and prevents adhesion of the excavated earth to the interior walls of the chamber. This ensures the smooth progress of tunnel excavation, since the excavation face is maintained in a balanced, stable condition. After excavation, the foamed soil is defoamed and the condition of the waste soil returns to nearly its original condition, thereby facilitating economical waste soil treatment and disposal.



Rheological Foam (microscopic photo, 60:1)

Enhanced Fluidity of Excavated Soil

For tunneling operations in gravel strata, the foam acts like ball bearings, so foam injection enhances the fluidity of the excavated soil. This eliminates the problem of clogging in the chamber, and facilitates more effective excavation performance since the cutter and screw conveyor can be operated at lower torques.

Minimized Pressure Variations at the Excavation Face

The injected foam is compressible and thus capable of accommodating earth pressure due to excavation. This minimizes pressure variation at the excavation face, maintains excavation face stability, and ensures regular cutter operation for improved excavation performance.

Enhanced Water-Sealing Properties

The interstitial ground water filling the gaps between soil particles is displaced and replaced by the finely-divided foam. This results in improved soil water-sealing properties, which facilitates excavation in sandy soils at high ground water levels, and also prevents soil eruption from the screw conveyor.

Protection Against Adhesion

During excavation in stiff clay soils, excellent excavation performance is also assured since foam injection prevents adhesion of the excavated earth material to the excavation face and/or chamber walls.

Rheological Foam Shield Tunneling Method - General Features

Easy Treatment and Disposal of Excavated Soil

After the injected foam has evaporated, the excavated soil returns to nearly its original condition, thereby facilitating the treatment and disposal of excavated soil.

Efficient Space Utilization with Compact Equipment

Compact injection and foam-generating equipment for the Rheological Foam Shield Tunneling Method facilitates the efficient use of space.

Improved Working Conditions

The Rheological Foam Shield Tunneling Method uses no clay or bentonite, so the tunnel work face remains uncontaminated and relatively clean. This results in better and safer site working conditions.

Foam Injection System

Foaming Solution Mixing Plant

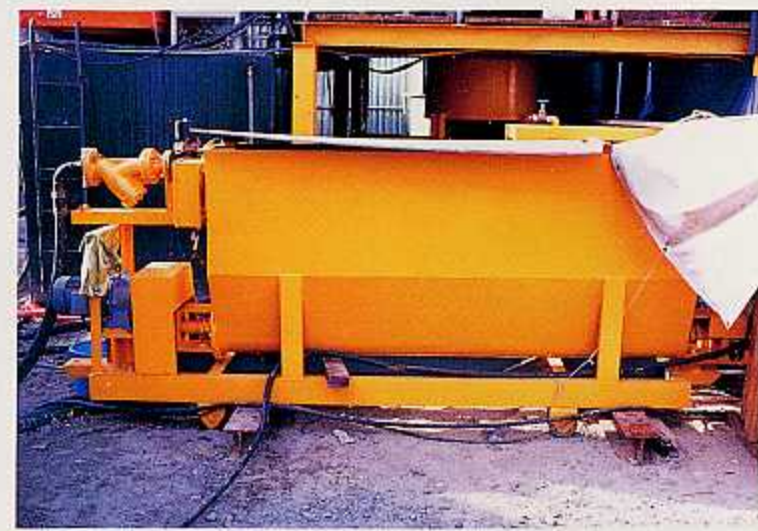


Foaming Solution Mixing Tank

Foam Injection Equipment



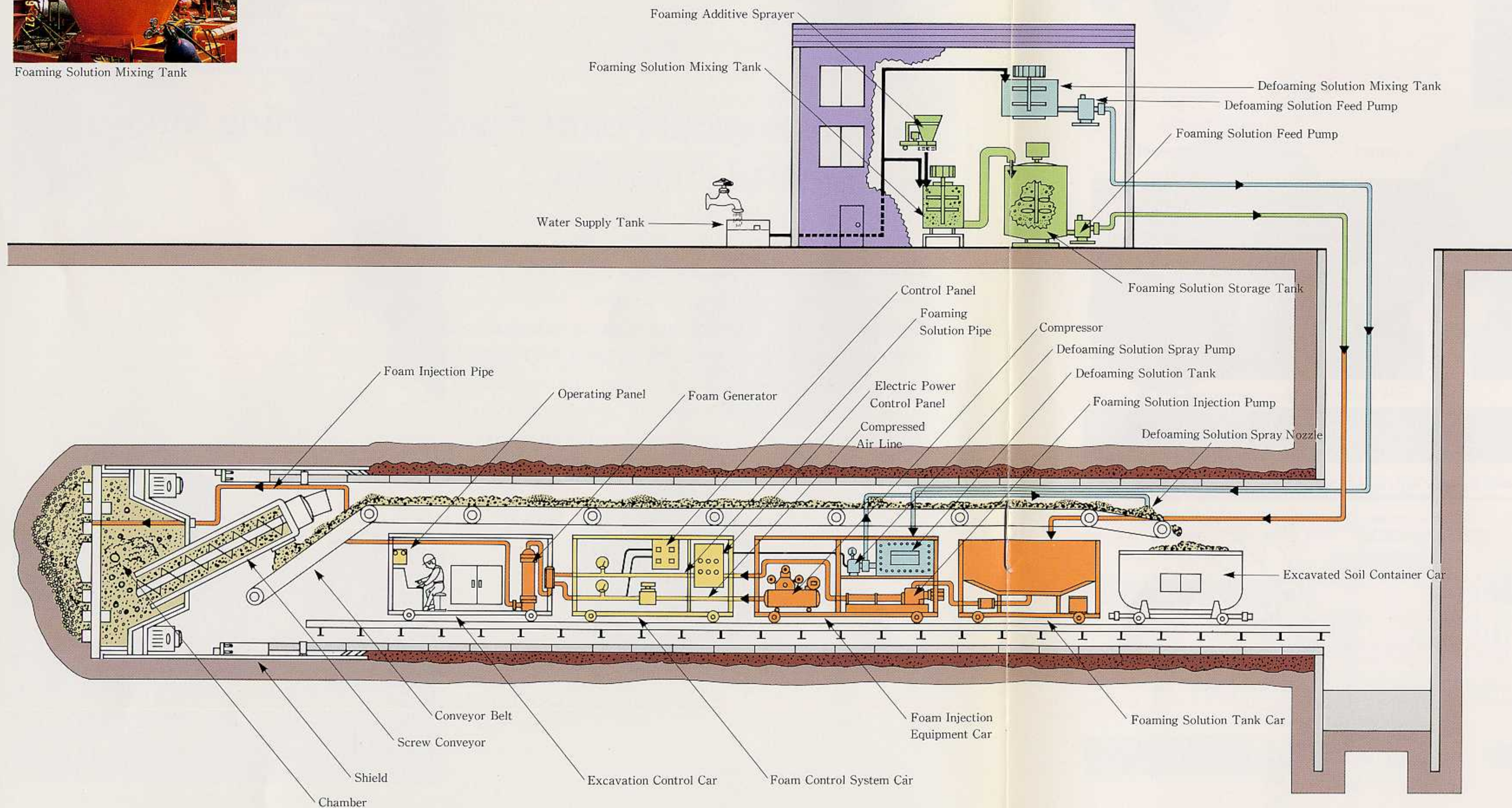
Foam Injection Equipment Car



Foaming Solution Tank Car



Foam Generator



Foam Control System

Automatically Controlled Injection Process

The Foam Control System is capable of real-time measurement of such critical conditions as tunnel excavation speed, internal chamber pressure (i.e., earth pressure at the excavation face), and cutter torque. It has a built-in micro-processor for automatic control and adjustment of the special foaming solution feed rate and the compressed air flow rate (as a compressible fluid) to ensure that the preset foam injection ratio and the within-chamber foaming ratio are constantly maintained at the proper optimum levels.



Foam Control System Car

Defoaming Equipment

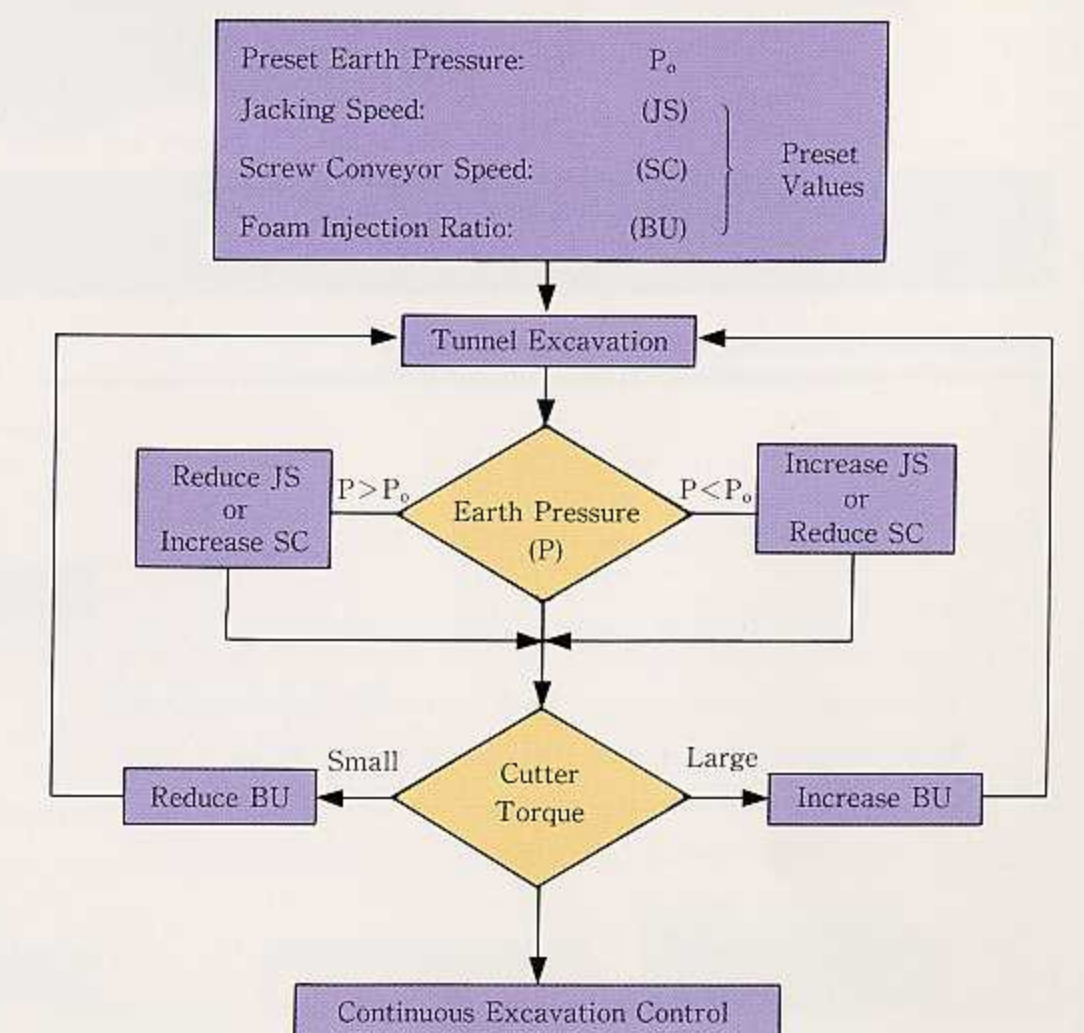
Effective Defoaming Capability

The defoaming equipment automatically controls the special defoaming solution spray amount in proportion to the volume of excavated soil to be defoamed. The spray method and position is varied according to the waste soil discharge method used.



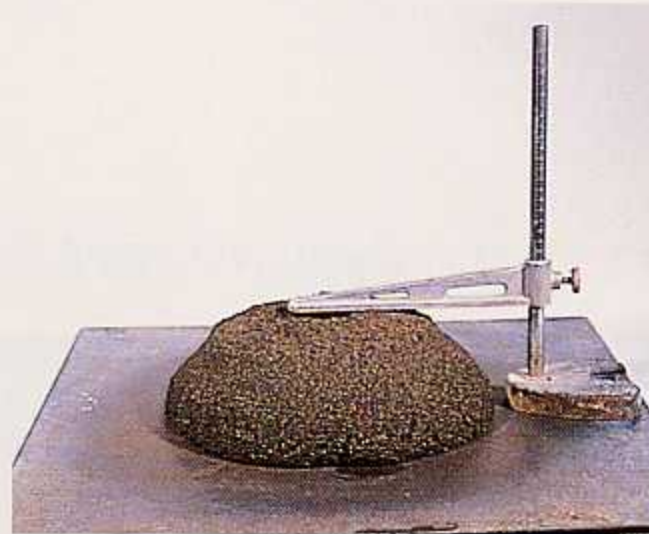
Defoaming Solution Spray Nozzle

Excavation Operation Control Chart

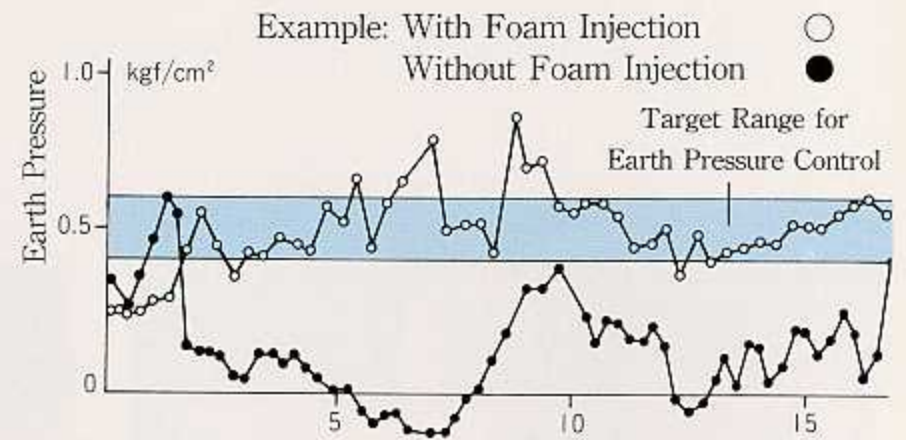


Foamed Soil Characteristics

Outstanding Fluidity

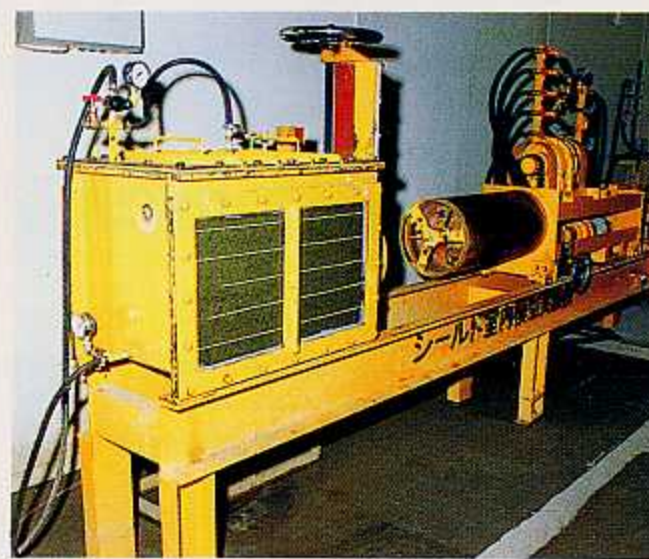


Foamed Soil Slump Test

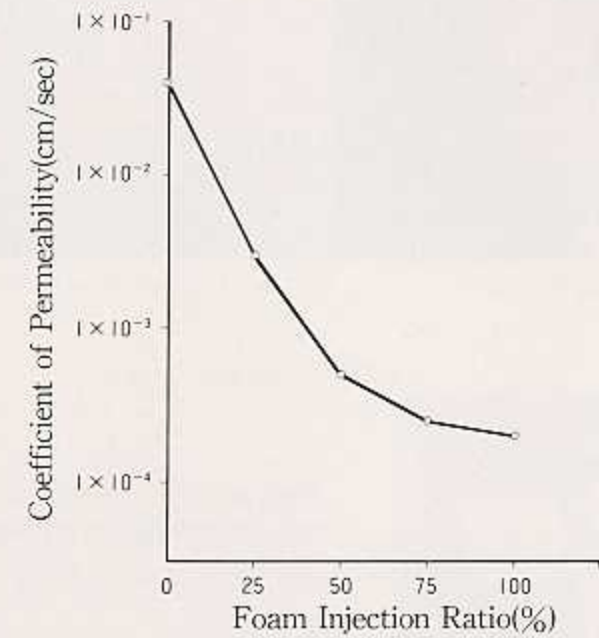


Excavation Speed Under Earth Pressure Control

Improved Water Sealing Performance



Simulation Test



Foamed Soil Coefficient of Permeability

Easy Treatment of Excavated Waste Soil



Discharged Excavated Soil Slump Test



Truck Loaded with Waste Soil for Disposal

Foam Injection Ratio

The Foam Injection Ratio (Injected Foam Volume/Excavated Soil Volume) is Determined Based on Soil Characteristics.

Formula for calculating the foam injection ratio*

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

If $Q(\%) < 20\%$, then $Q = 20\%$

Where X = percentage by weight passing a 0.075mm sieve (If $4 \times X^{0.8} > 60$, then $X = 60\%$)

Y = percentage by weight passing a 0.42mm sieve (If $3.3 \times Y^{0.8} > 80$, then $Y = 80\%$)

Z = percentage by weight passing a 2.0mm sieve (If $2.7 \times Z^{0.8} > 90$, then $Z = 90\%$)

α is a coefficient based on the Uniformity Coefficient, U_c ($U_c = D_{60}/D_{10}$)

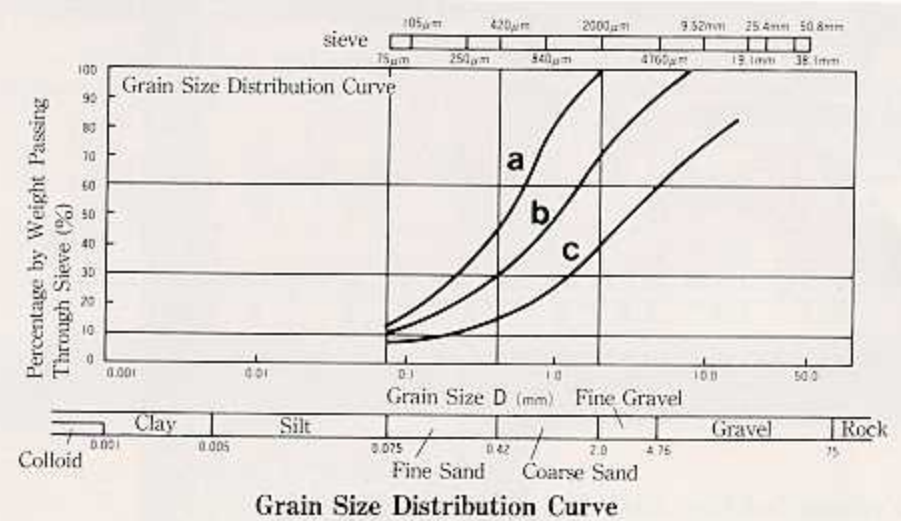
If $U_c < 4$, then $\alpha = 1.6$

If $4 \leq U_c < 15$, then $\alpha = 1.2$

If $15 \leq U_c$, then $\alpha = 1.0$

*If foam injection is used to prevent adhesion, the standard foam injection ratio, Q , should be set to 30%.

Foam Injection Ratio by soil Characteristics (Example)



Foam Injection Ratio

Soil Characteristics	Foam Injection Ratio
a	24%
b	37%
c	65%

Materials and Agents Used

Special Foaming Agent

OK-1

Surfactant preparation specially formulated for superior foaming performance when applied to soil during tunnel excavation.

Foaming Additive

OK-2

Foam stabilization additive whose solutions impart outstanding lubricating and water retention properties.

All Materials Are Non-Polluting

Special Foaming Solution(1m³)

		TypeA	TypeB
Standard Ratio	OK-1	30 ℓ	10 ℓ
	OK-2	-----	12 kg
	Water	970 ℓ	978 ℓ
Properties	pH	7.6	7.3
	Specific Gravity	1.00	1.00
	Viscosity(20°C)	2.7cP	300cP

Note: Type A or Type B special foaming solutions are specified according to soil type.

Special Defoaming Solution(1m³)

Standard Ratio	OK-01	100 ℓ
	OK-02	2 kg
	Water	898 ℓ
Properties	pH	6.4
	Specific Gravity	0.99
	Viscosity(20°C)	2.5cP

Surfactant mixture with rapid foam breakdown action to defoam air bubbles in the foamed soil.

Special Defoaming Agent

OK-01

Hydrolytic enzymes added to promote the foam breakdown effect of the special defoaming agent.

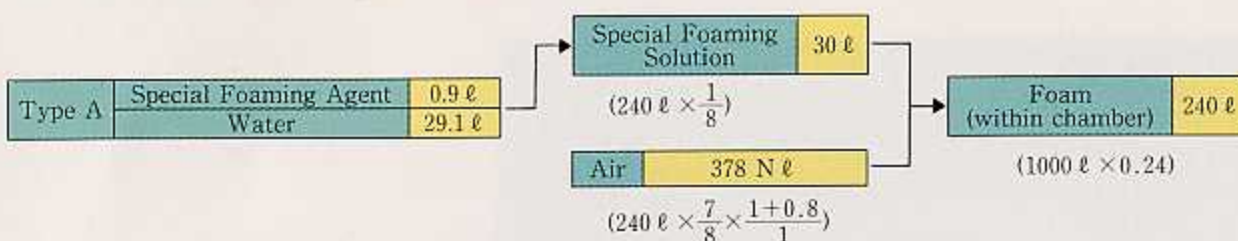
Defoaming Additive

OK-02

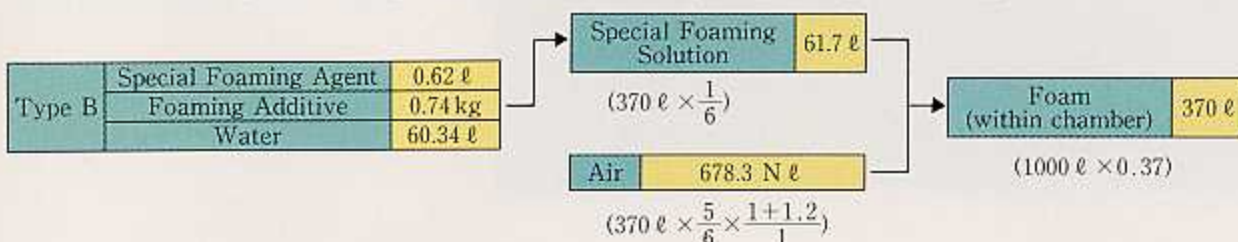
Calculation of Material Additions (Example)

Special Foaming Solution

For the soil grade, a, of page 5: Q=24%, and an internal chamber pressure of 0.8kgf/cm², the foaming ratio (foam volume/special foaming solution volume)=8 for special foaming solution Type A.

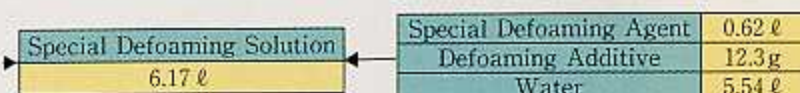


For the soil grade, b, of page 5: Q=37%, and an internal chamber pressure of 1.2kgf/cm², the foaming ratio (foam volume/special foaming solution volume)=6 for special foaming solution Type B



Special Defoaming Solution

(Note: Use of the special defoaming solution is optional.)



MEMBERS OF THE RHEOLOGICAL FOAM SHIELD TUNNELING METHOD ASSOCIATION

Aisawa Construction Co.,Ltd.
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Asanuma Corporation
Chizaki Kogyo Co., Ltd.
Daiho Construction Co., Ltd.
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