Effects of bituminous layer as backfill material on mechanical behavior in tunnel model

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ABSTRACT

This paper describes the effects of bituminous material as a backfill material on mechanical behavior in model tunnel in laboratory. It is known that load spreading and relaxation of bituminous material are good properties. Then if we use bituminous material as a backfill material of tunnel, the tunnel will have waterproof, good load spreading property. We used new bituminous material (Aquaphalt) which can solidify in water. We conducted relaxation test in tension for new bituminous material at various temperatures and obtained relaxation modulus of bituminous material at various temperatures. We performed experiment with line load for plastic tube (Diameter: 30cm) with or without bituminous material (thickness: 3cm) and compared with the results of theoretical analysis using FEM visco-elastic soft program and relaxation modulus of bituminous material which was obtained by relaxation test in tension. As the results, if load applied to the tunnel with bituminous material, strain and stress induced with load in plastic tunnel model decreased, comparing with that of without bituminous material and coincided with theoretical results. Then, it is concluded that it is very effective to use bituminous material as a backfill material to tunnel in order to obtain larger load spreading properties.

1. INTRODUCTION

It is very important to prevent icicles hanging in road tunnel in cold areas. But, urethane injection method for tunnel was prohibited in 1995, because prevention of ozone hole, Hokkaido, Japan. It was been long desired to develop new material for insulating material of tunnel. We developed new material which can solidifies in water. It consists of asphalt emulsion, cement, insulating material and hardening agents[1, 2,3,4,5]. We had already used it under concrete pavement in tunnel in order to decrease of damping due to moving vehicles and prevent the frost heaving in cold areas[6]

This paper describes the effects on mechanical behavior in tunnel with bituminous material as a backfill material in mini-tunnel model. We performed relaxation test in tension for new material and obtained relaxation modulus for various temperature. Then, we calculated strain under vinylchloride tube with new material using visco-elastic FEM theory and also performed the test using same line load on model tunnel. As the test results, if we use for tunnel with bituminous material as a backfill material, we found that load spreading properties due to eccentric load and thermal load remarkably increased, comparing with that of without bituminous material as a backfill material. Good correlation exists for both strains under vinylchloride tube for experiment and simulation

2. TEST POCEDURES AND MATERIAL

Experiment of tunnel model with bituminous material and urethane foam of hard type using loading apparatus were performed. Composition of new bituminous material was given in Table 1.

Table 1 Composition of new bituminous material as a backfill material

Material	Weight (%)
Asphalt Emulsion (Penetration 60)	47.3
Portland Cement	14.2
Insulating Material	
Glass bees 〔2.5-1.2 mm〕	18.9
Glass bees 〔1.2-0.6 mm〕	18.9
Sodium Silicate	0.6

Table 2 Thermal properties of materials

Material	Coefficient of expansion (1/℃)	Thermal conductivity (kcal/mh℃)	Specific heat (J/g℃)
New Material (Bituminous type)	4.26×10^{-5}	0.20	879.0
Vinylchloride	1.2×10^{-4}	1.16	1256.0

Table 3 Mechanical properties of materials

Material	Density (g/cm^3)	Poisson's ratio	Elastic modulus (MPa)	Compressive strength (MPa)
New Material (Bituminous type)	0.7	0.45		
Vinylchloride		0.48	$2.0x10^4$	
Urethane	0.12			1.5

Table 2 and Table 3 show that thermal and mechanical properties of materials.

Tube made of vinylchloride (Thickness:10 mm, Inner Diameter:30 cm, length:15 cm) was used as mini-tunnel model. Backfill materials of 3 cm thickness were covered on tube.

2. TEST PROCEDURE

Direct relaxation test in tension for new material (size of specimen: 2.5x2.5x10 cm) was conducted under –10-20℃ under instantaneous deformation of 0.05 mm and obtained relaxation modulus of this material for each 5℃. We prepared master curve and shift factor for new material at reference temperature 5℃.

Loading for mini-tunnel with or without backfill materials were performed using hydraulic machine up to 20 kgf under line load on location of 12 o'clock. Strain gauges on inside of vinylchloride tube at location of 12 o'clock, 1 o'clock, 2 o'clock, 3 o'clock were attached and measured strains using recorder at every location when it was loaded.

3. STRESS ANALYSIS

Stress analysis was conducted by visco-elastic FEM method of hybrid type. Firstly, circular tunnel model was cut by quarter section, and we defined that X-direction was fix and Y- direction was roller at location of 12 o'clock, whereas

X-direction was roller and Y-direction was fix at location of 3 o'clock. Figure 1 shows that triangle meshes of this structure were 108 and node numbers were 76 and tube was one layer (1cm thickness) and backfill material was made of 2 layers (3 cm thickness). We obtained master curve (Figure 2) for bituminous material at reference temperature 5 ℃ using various relaxation modulus and shift factor (Figure 3), and approximated prony series function (2) in substitute of master curve.

We applied to trapezoidal approximation for equation (1).

$$\sigma(t) = E(0)\varepsilon(t) - \int_0^t \frac{dE(t-t')}{dt'}\varepsilon(t')dt' \cdots (1)$$

$$E(t) = A_0 + \sum_{j=1}^{q} A_j e^{-\frac{t}{\tau j}} \cdots (2)$$

where, σ (t) and ε (t) are uniaxial stress and strain. E(t) is the uniaxial stress relaxation modulus defied as the stress response to a unit step strain.

Assuming constant bulk modulus, K, and constant coefficient of thermal expansion, α, we can obtain stiffness equations (3) for an element. The element stresses are written for the element centroid since temperature is permitted to vary linearly in each element.

$$(K1 + [G(0) - G(\xi_k - \xi_{k-1})]K2)q(t_k) = F(t_k) + H(t_k) + V(t_k) \cdots (3)$$

G : Relaxation modulus in shear、q : Deformation、 ξ : Shift time、
K1,K2 : Constant、
F : Mechanical load、H : Thermal load、V : Memory load

It was assumed that bottom temperature of backfill material was 5℃ and ambient temperature in tunnel changed with time as shown in Figure 4.

We checked both measured and calculated strain on vynylchloride tube with or without new material and urethane under mechanical and thermal loading when ambient temperature changed. We assumed the values of elastic modulus $2x10^4$ kgf/cm^2 for vinylchloride.

4. EXPERIMENTAL RESLUTLS AND SIMULATION

4.1 Line loading to tube without back fill material

Tube without backfill material was loaded 20 kgf by line load at location of 12 o'clock. Figure 5, 6 and Table 4 show that maximum strain of Y

–direction of bottom surface of tube at location of 12 o'clock was measured 776×10^{-6} (calculated value: 800×10^{-6}), whereas, maximum strain of X –direction of bottom surface of tube at location of 3 o'clock was measured 644×10^{-6} (calculated value: 560×10^{-6}). Good correlation for both results was obtained.

Table 4 Results of measured and calculated maximum strain without backfill material ($\times 10^{-6}$)

Location	12 o'clock	3 o'clock
Measured	776	644
Calculated	800	560

4.2 Line loading to tube with new material (3 cm: thickness)

Tube with new material was loaded 20 kgf by line load at location of 12 o'clock. Figure 5 and 6 and Table 5 show that maximum strain of Y –direction of bottom of tube at location of 12 o'clock was measured 570×10^{-6} (calculated value: 510×10^{-6}), whereas, maximum strain of X –direction of left end of tube at location of 3 o'clock was measured 330×10^{-6} (calculated value: 380×10^{-6}).

Table 5 Results of measured and calculated maximum strain with new material ($\times 10^{-6}$)

Location	12 o'clock	3 o'clock
Measured	570	330
Calculated	510	380

Correlation for both results was good.

Figure 7 shows the test results of line loading for tunnel with new material at location of 3 o'clock. When, apparatus was stopped at 20 kgf, thereafter its deformation maintains constant. After stopping of apparatus, strain under vinylchloride tube was measured and measured values were decreased with time. It means that stress relaxation of bituminous material in compression side occurred in bituminous material.

4.3 Line loading to tube with urethane foam

Tube with urethane foam was loaded 20 kgf by line load at location of 12 o'clock. Figure 7 shows the test results of line loading for tunnel with urethane foam at location of 3 o'clock. When, apparatus was stopped at 20 kgf, thereafter its deformation maintains constant. After stopping of apparatus, strain under vinylchloride tube was measured. We found that relaxation properties of new material is superior to that of urethane foam.

Table 6 Results of measured maximum strain with new material, urethane foam and without backfill material (vinylchloride only) ($x10^{-6}$)

Location	12 o'clock	3 o'clock
New material	570	330
Urethane foam	426	267
vinylchloride	776	644

4.4 Simulation of thermal stress with or without new material

Figure 8 shows the thermal stress for each 2 hour under vinylchloride tube of X-direction at location of 12 o'clock. Thermal stress of tube with new material is a little smaller than that of without new material over the whole time. It means that the former was very effective for relaxation of thermal stress.

5. CONCLUSIONS

The following conclusions were obtained in this study.

(1) Similar maximum strains were obtained for both results of experiment and

simulation for model tunnel with or without bituminous material.

(2) Good load spreading properties of bituminous material as backfill material was examined.

(3) Load spreading properties of bituminous material was superior to that of urethane material.

(4) Thermal stress in vinylchloride tube with bituminous material as backfill material due to ambient change in tunnel was smaller than that of only vinylchloride tube.

(5) It is considered that tunnel with bituminous material as backfill material is very effective for eccentric load and thermal load.

(6) It is considered that tunnel covered with bituminous material including in insulating material would be effective for water proof, load spreading, insulating layer and anti-earthquake.

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FIGURE CAPTION

FIGURE 1 Triangle mesh of quarter model tunnel for FEM

FIGURE 2 Master curve of bituminous material at reference temperature 5℃

FIGURE 3 Shift factor of bituminous material at reference temperature 5℃

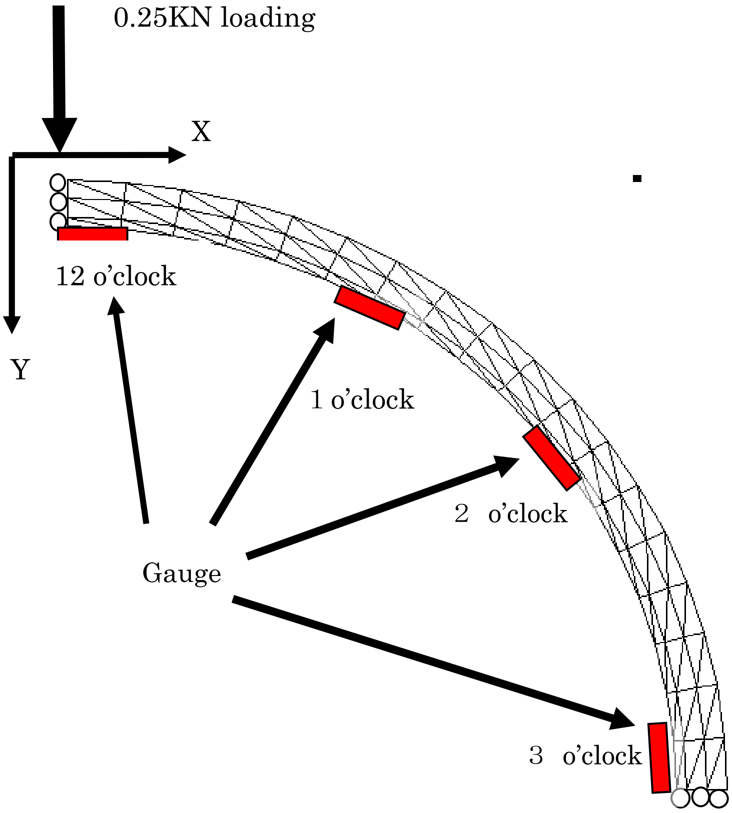
FIGURE 4 Ambient temperature change with time at tunnel

FIGURE 5 Calculated X-direction strain at location of 12 o'clock for with or without bituminous material

FIGURE 6 Calculated Y-direction strain at location of 3 o'clock for with or without bituminous material

FIGURE 7 Measured strain – time curves at location of 3 o'clock for with new material and urethane foam

FIGURE 8 Calculated thermal stresses –time curves with or without bituminous material



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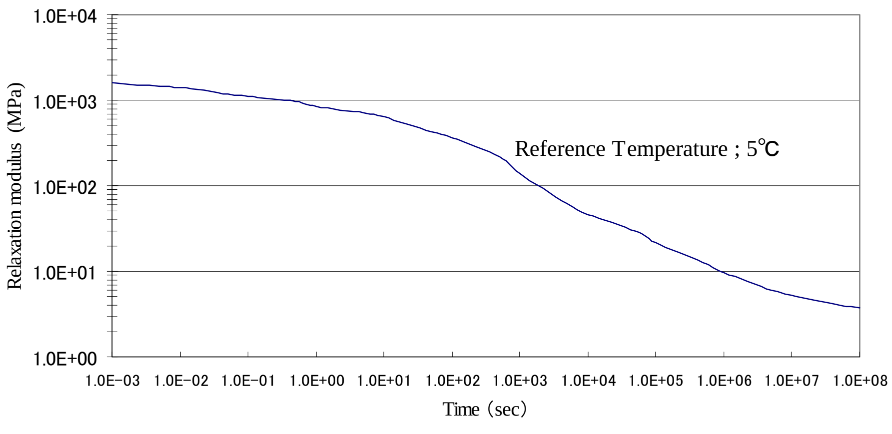

FIGURE 2 Master curve of bituminous material at reference temperature 5℃

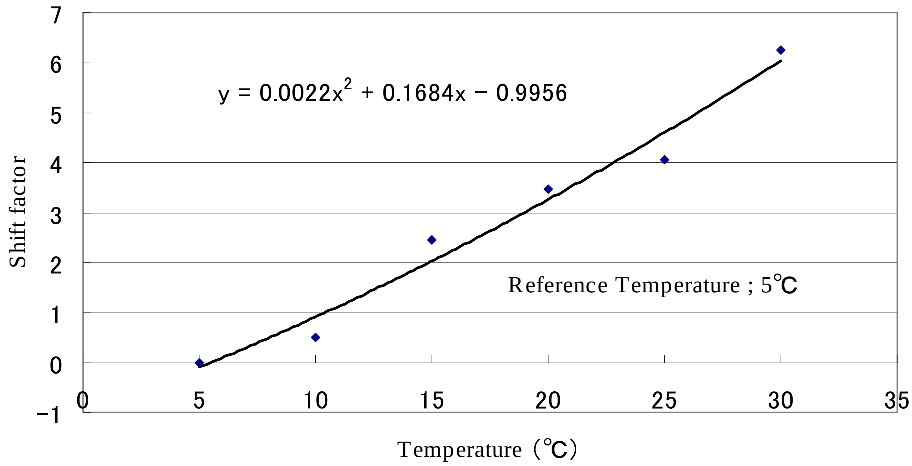

FIGURE 3　Shift factor of bituminous material at reference temperature 5℃

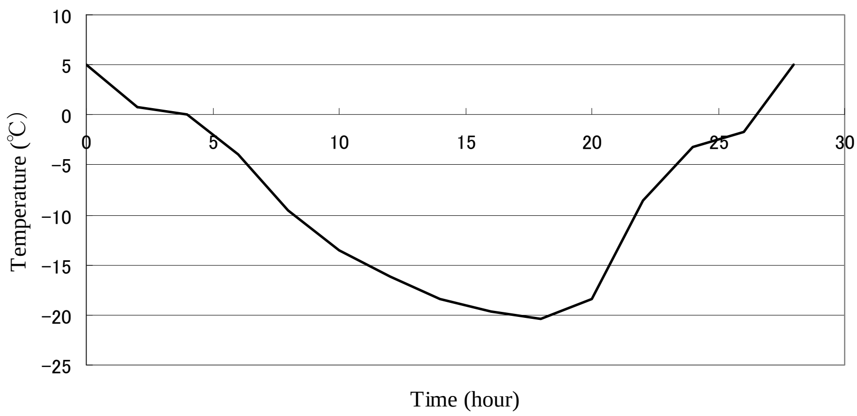

FIGURE 4　Ambient temperature change with time at tunnel

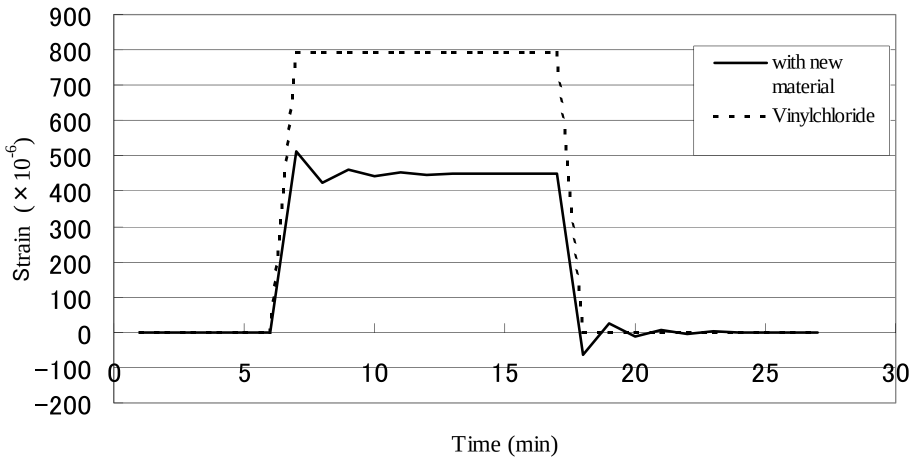

FIGURE 5　Calculated X-direction strain at location of 12 o'clock for with or without bituminous material

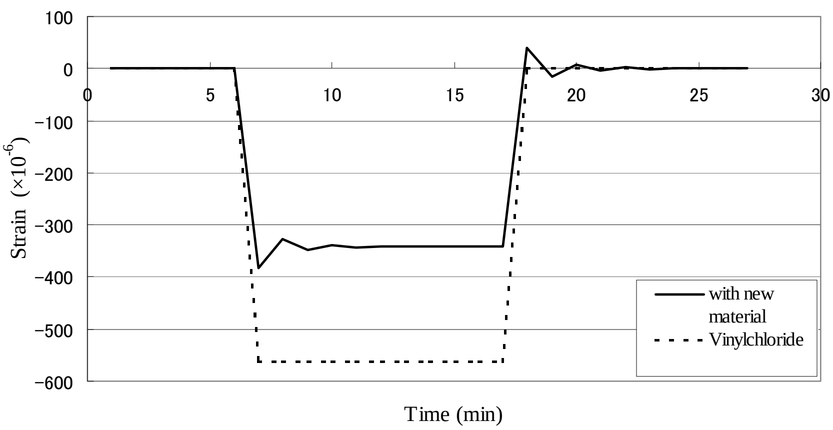

FIGURE 6　Calculated Y-direction strain at location of 3 o'clock for with or without bituminous material

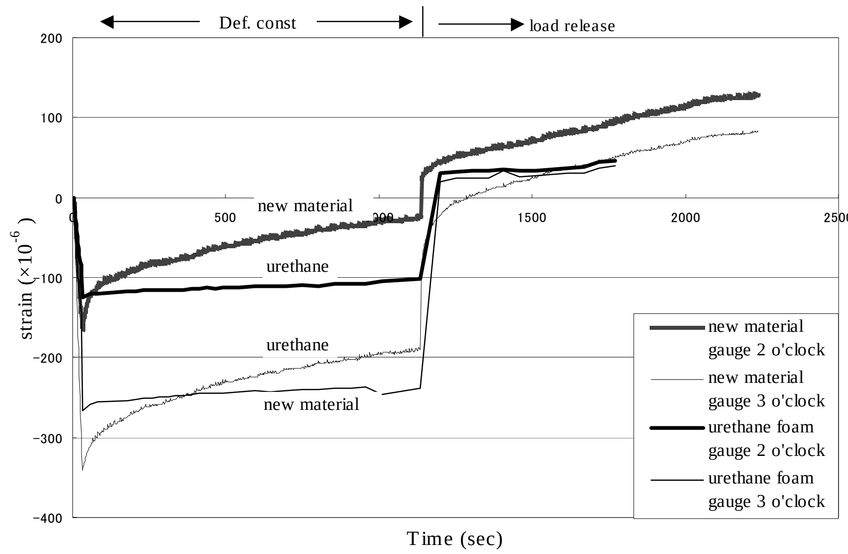

FIGURE 7 Measured strain – time curves at location of 3 o'clock for with new material and urethane foam

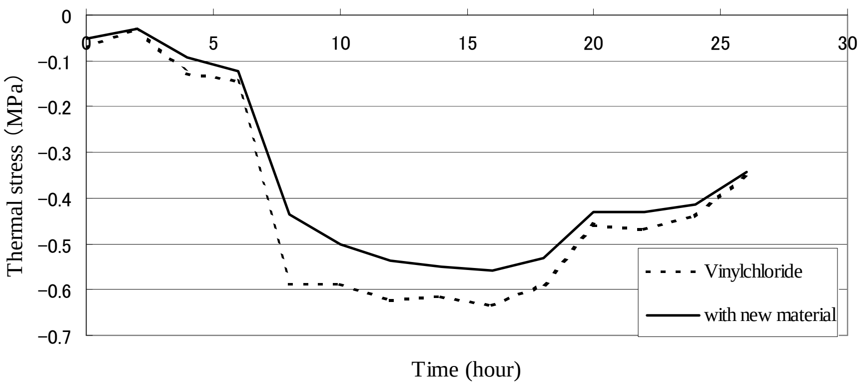

FIGURE 8 Calculated thermal stresses –time curves with or without bituminous material

Table 1 Composition of new bituminous material as a backfill material
Table 2 Thermal properties of materials
Table 3 Mechanical properties of materials
Table 4 Results of measured and calculated strain without backfill material ($x10^{-6}$)
Table 5 Results of measured and calculated strain with backfill material ($x10^{-6}$)
Table 6 Results of measured strain with new material and urethane material ($x10^{-6}$)