Damage analysis of flexible pavement in SWISS at high and low temperature using hybrid visco-elastic FEM

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ABSTRACT

This paper describes stress and deformation analysis for different damage in flexible pavement at high and low temperature using hybrid visco-elastic FEM and relaxation test results in tension for bituminous mixtures, which were performed at different temperatures. Cracking due to thermal load and rutting are a big concern in flexible pavement. But, recently, many researchers had been reported that longitudinal cracking under wheel path at high temperature occurred. This cracking never occurred in surface pavement covered by overbridge in summer.

We tried to analyze the cause of longitudinal cracking under wheel path at high temperature and thermal stress in flexible pavement at low temperature using hybrid visco-elastic FEM. This paper consists of experiment of relaxation modulus for bituminous mixtures taken from fields and stress analysis using hybrid visco-elastic FEM. Apparatus in order to measure relaxation modulus was modified in our laboratory.

It was concluded that longitudinal cracking was caused by large shearing force due to radial tire of automobiles at high temperature and thermal stresses due to thermal load were almost the same for both rutting and longitudinal cracking sections in Swiss.

1. INTRODUCTION

Main damage of highway in the world was rutting, but longitudinal cracking was also a big concern (1,2,3). Damage analysis such as longitudinal cracking of flexible pavement at high temperature and stress analysis due to thermal load at low temperature were performed using hybrid visco-elastic FEM. We assumed pavement structure model to analyze various damages using triangle mesh for real pavement structures. Relaxation test in tension for each of bituminous mixtures were conducted and obtained relaxation

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modulus and shift factor. We applied it prony series function for approximation. As the test results, it was concluded that longitudinal cracking would be caused by shearing force of perpendicular to moving tire in high temperature and thermal stresses due to thermal load were almost the same for both rutting and longitudinal cracking sections in Swiss (4).

2. Material and Test section

We selected 2 test roads: one is an A3 national road (G section and H section) and other is a Japan Express highway (Usu city), Hokkaido, in Japan (Table1). We took the bituminous mixtures from these test roads, such G (4 layers) and H (4 layers) section belong to A3 road near Zurich and surface course in both cracked and non-cracked section of longitudinal cracking in Japan. Severe rutting occurred in pavement of G section and longitudinal cracking under wheel path occurred in pavement of H section. Table 1 shows that material characteristics and sampling data of surface course, binder course, upper base course and lower base course in Swiss and surface course in Japan.

Typical longitudinal cracking under wheel path also occurred in Express highway (Usu city), in Japan. We took the specimens (surface course: 3 cm) from cracking and non-cracking section near cracking section. Both surface deformations using falling weight deflectometer (FWD) at cracked and non-cracked section were the same (5).

We used mixtures for direct tension and relaxation test using the mixtures of Swiss and Japan for different temperatures (6).

3. Analytical method

Typical pavement model for G and H pavement sections is shown in Figure1. We defined that X-direction (perpendicular with vehicle direction) was fix and Y- direction was roller at both side ends of these models. This model consists of width 100 cm, depth 100 cm and was utilized triangle mesh (1cm: width, 1cm: height). Width of tire was assumed in 20 cm width and 5-ton wheel load (outer shearing force (3kg/cm) to left and right sides from center of tire) was applied. Loading time of automobiles was 0.18 second. It corresponds to automobiles speed of 60 km/h. Wheel load was applied to model at high temperatures. Whereas, thermal stress due to change of temperature for this model was calculated using ambient temperature at winter of Figure 2 (7).

Figure 1 consists of triangle meshes for these structures were 22600 and numbers of node were 11514 and bituminous layer consists of 4 layers. We assume that both side ends were adiabatic state and surface temperature in asphalt pavement was about 50℃ and 38℃ in summer, and bottom temperature of subgrade (100 cm) was 3℃ and surface temperature of bituminous pavement was obeyed by law of Newton cooling.

We obtained master curve (Figure 3) for bituminous material of G and H pavement sections at reference temperature 0℃ using various relaxation modulus and shift factor, and approximated prony series function in substitute of master curve.

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We calculated stress, strain and deformation due to change of ambient temperature and wheel load using hybrid visco-elastic FEM and master curve.

４． Test method

We performed following tests for bituminous mixtures. Relaxation test (-15-60℃) in tension for bituminous mixtures (size: 2.5x2.5x10 cm, instantaneous deformation:0.05 mm, one specimen/one temperature) for G and H section in Swiss was conducted using Electro-Hydraulic Servo machine (Instron: 1350 type). It was modified in our laboratory. We also measured coefficient of expansion and extraction for bituminous mixture using contact gauge of cement concrete.
Direct tension test (5-50℃) was performed for surface mixtures taken from cracked and non-cracked section in Japan. Rate of strain was $3.4x10^{-3}$ 1/sec. Specimen size for both tests of tension and relaxation is 2.5x2.5x10cm and we used one specimen at each temperature .

５． Results and discussion

5.1 Stress analysis for longitudinal cracking

Figure 4 shows the relation between tensile strength and temperature for bituminous mixtures (surface layer) of cracking section and non-cracking section in Japan. Strength of bituminous mixture in cracking section was a little smaller than that of non-cracking section in high temperature. Figure 5 shows the relation between stiffness at failure and temperature. If we compared with stiffness at failure at high temperature for both mixtures, stiffness at failure temperature of cracking section was 4-5℃ lower than that of non-cracking section. Frequency of 48℃ in maximum surface temperature was 55 times in 1999, frequency of 51℃ was 22 times in 1999. frequency of 54℃ was 8 times in 1999. Whereas, frequency of 48℃ in maximum surface temperature was 33 times in 1998, frequency of 51℃ was 9 times in 1998. frequency of 54℃ was 0 times in 1998.
Whereas, maximum temperature of 46.8℃ under 2 cm was recorded in 1998 at Zurich. Tensile strength of bituminous mixtures for longitudinal cracking area (H section) and rutting area (G section) in Swiss were 0.12 MPa in non-cracking area, 0.092 MPa in cracking area at 50℃, $3.4x10^{-3}$ 1/sec of strain rate.
Moreover, it was reported that shearing force on surface pavement perpendicular to tire center of radial tire was 2-3 kg/cm at traffic condition (8). Table 2 shows simulation results of shearing force (3kg/cm) due to radial tire by hybrid visco-elastic FEM theory for pavement structure of Figure 1 at surface temperature of 50℃ and 38℃. Temperature distribution in pavement was calculated by thermal conductivity equation. We found that larger shearing stress perpendicular to tire due to radial tire on the surface of pavement at high temperature occurs, comparing with without shearing force. It is considered that shearing stress due to radial tire on pavement surface in cracking section

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will exceed tensile strength of bituminous mixture at high temperature in described before. We had already checked that shearing stress on pavement surface at the mid point of tire (point C in Figure 1) perpendicular to radial tire was the largest in all tires, especially for tire of heavy vehicles. Then, it is considered that longitudinal cracking under wheel path at high temperature was caused by shearing force due to radial tire of heavy car, when critical value of tensile strength at high temperature will exceed at certain value (1kg/cm^2). But surface deformation changes rather than stress and/or strain due to wheel load at high temperature in Table 2.

5.2 Rutting analysis for H and G section in Swiss

Rutting in G section occurred in the field and longitudinal cracking mainly occurred in H section. The shapes of relaxation modulus –time curves for mixtures of both sections were different with each other, especially degree of relaxation for G section was remarkably better than that of H section for every temperature. Table 3 and 4 show the minimum relaxation modulus for both layers at long time and high temperature. These results mean that rutting of G section will be larger than that of H section. We are now examining the degree of rutting for both sections, considering with characteristics of mixtures using hybrid FEM visco-elastic theory and relaxation modulus of different mixtures.

5.3 Analysis of thermal stress

We calculated maximum thermal stress on pavement surface for both pavement models (G section and H section) using ambient temperature change from 0℃to -22.5℃. Figure 6 shows the relation between thermal stress on pavement surface and time for both sections. Maximum thermal stress of both G (0.24MPa) and H (0.27MPa) sections will occur at 7 hours, not at minimum ambient temperature (16 hours). It was very small, comparative with normal tensile strength of mixtures (4-6 MPa at low temperature)

６. Conclusions

We obtained the following results.

1) Longitudinal cracking and thermal stress analysis in high and low temperatures will be performed by hybrid visco-elastic FEM theory.

2) It is considered that longitudinal cracking in bituminous pavement would occurred by shearing force due to radial tire of heavy vehicles.

3) Tensile strength of surface course in longitudinal cracking section was a little smaller than that of non-cracking section in high temperature.

4) Relaxation modulus of bituminous layers at high temperature will affect on surface rutting in bituminous pavement in Swiss.

5) Thermal stress on pavement surface in Swiss is small, comparative with normal strength of mixtures.

6) Maximum thermal stress in both sections in Swiss will occur at 7 hours, not at

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minimum ambient temperature (16 hours).

7. References

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Table 1 Material characteristics and sampling data of surface course, binder course, upper base courses and lower base course in Swiss (ESALs/lane:6.1mio, Service time: 6 years) and surface course in Japan (Service time: 3 years)

Section Country	G Swiss	H Swiss	Cracked Japan	Non-cracked Japan
Surface course	AB16	TA16		
Binder Type	B80/100	TB2000	B60/80	B60/80
Trinidad Epure (%)	1.25	1.25		
Max. Aggregate size (mm)	16	16	19	19
Binder content (%)	6.14	5.64	6.2	6.2
Air void content (%)	3.5	2.6	3.0	3.0
Thickness (mm)	30	37	40	40
Max. deformation (mm)	6.2	3.6	0	0

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Binder course	AB16	TA16
Binder Type	B80/100	TB2000
Max. Aggregate size (mm)	16	16
Binder content (%)	5.44	5.3
Air void content (%)	4.7	4.8
Thickness (mm)	43	31
Max. deformation (mm)	5	0.2
Upper base course	HMT32	HMT32
Binder Type	B80/100	TB2000
Max. Aggregate size (mm)	32	32
Binder content (%)	4.06	4.24
Air void content (%)	2.6	3.7
Thickness (mm)	77	53
Max. deformation (mm)	3	1.3
Lower base course	HMT32	HMT32
Binder Type	B80/100	TB2000
Max. Aggregate size (mm)	32	32
Binder content (%)	3.95	3.82
Air void content (%)	2.3	3.9
Thickness (mm)	91	81
Max. deformation (mm)	3	0.5

Table 2 Behavior of pavement surface due to tire at 38℃ and 50℃ at point C

38℃

No Shear

G point	Stress(MPa)	Strain	Def.(cm)
C	5.4E−3	3.2E−6	6.0E−7
H			
C	4.7E−3	3.2E−6	7.3E−7

Shear

G point	Stress(MPa)	Strain	Def.(cm)
C	9.3E−2	6.2E−6	6.3E−7

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H

C 8.4E－2 6.8E－6 7.7E－7

50℃

Shear

G	Stress(MPa)	Strain	Def.(cm)
C	9.3E－2	6.2E－6	1.9E－6
H			
C	8.4E－2	6.8E－6	2.4E－6

Table 3 Minimum relaxation modulus (kg/cm^2) in long time and high temperature

Layer	H section	G section
1st	450	350
2nd	150	35
3rd	60	25
4th	15	15

Table 4 Time (sec) corresponding to 1000 kg/cm^2 at 20 ℃ for each layer

Layer	H section	G section
1st	100	10
2nd	100	3
3rd	400	8
4th	100	10

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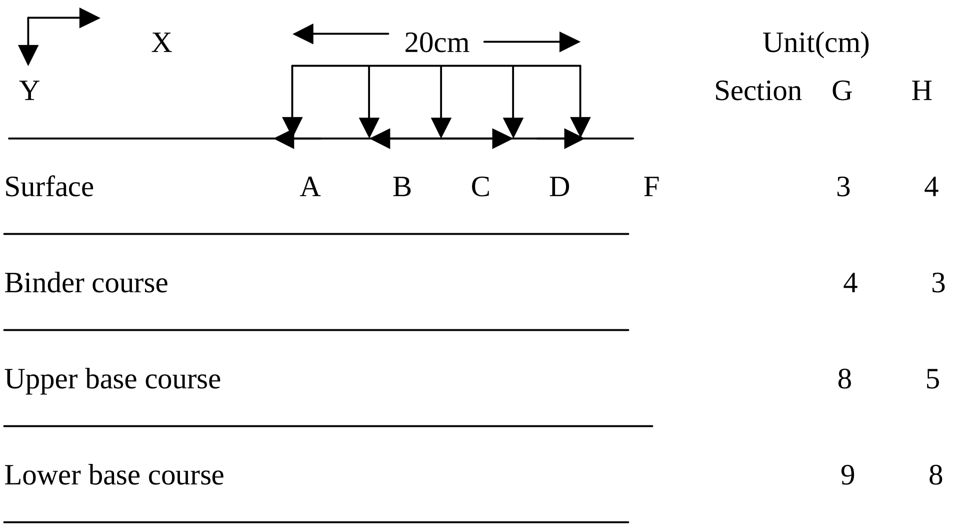

Figure 1 Pavement model with shearing force due to radial tire

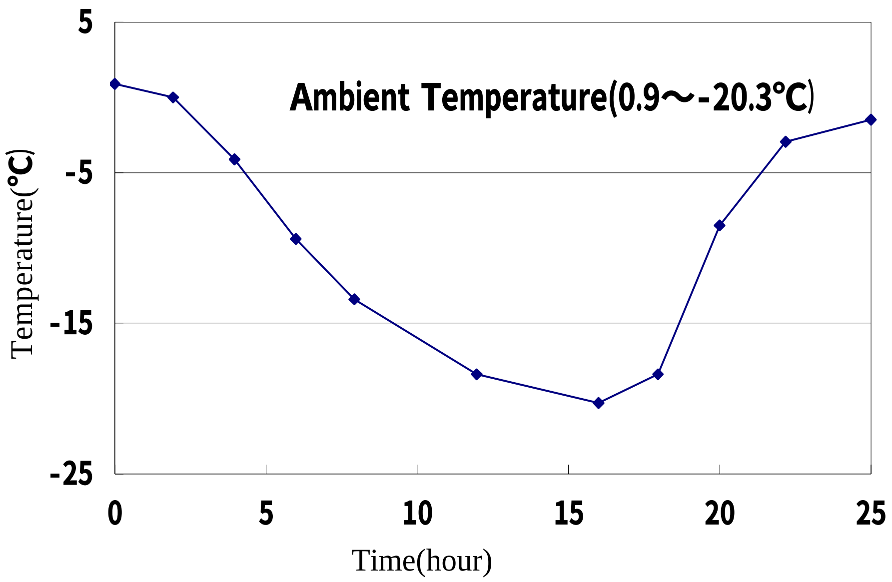

Figure 2 Ambient temperature

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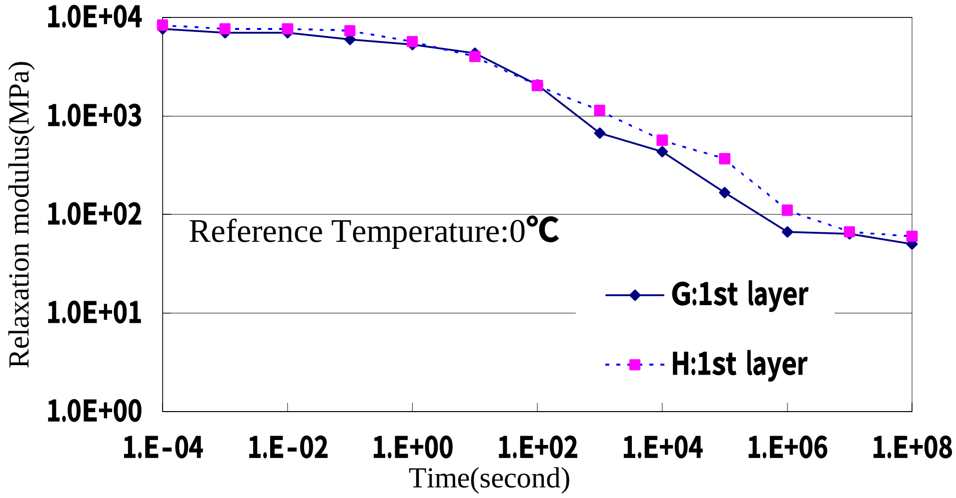

Figure 3 Relation between relaxation modulus and time

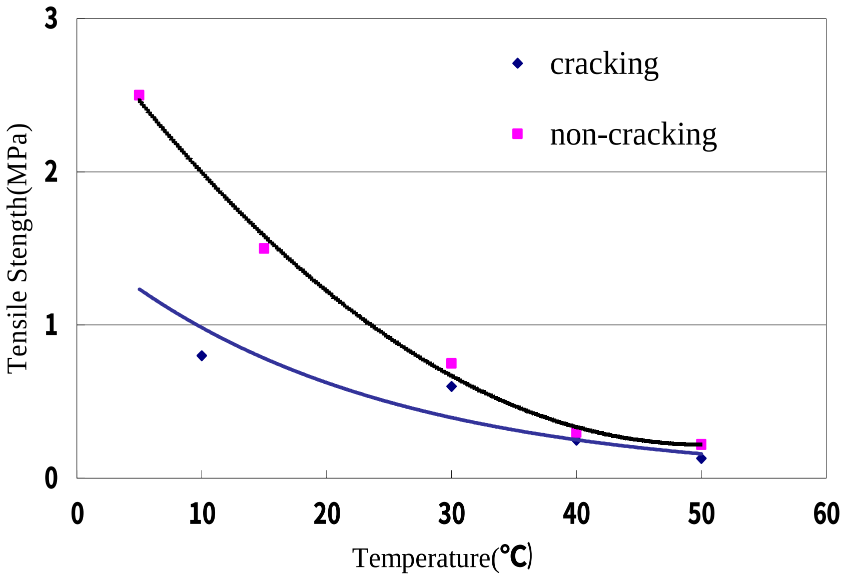

Figure 4 Relation between tensile strength and temperature

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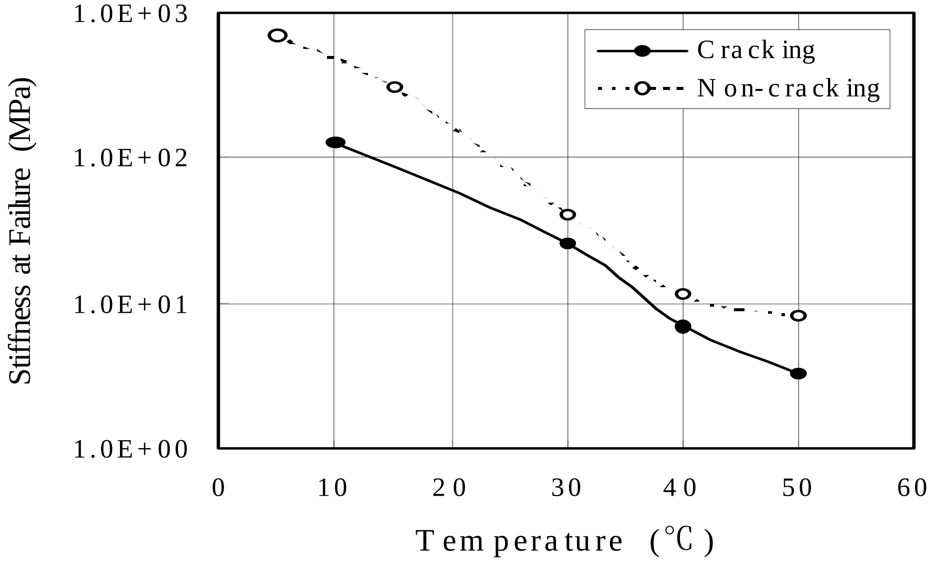

Figure 5 Relation between stiffness at failure and temperature

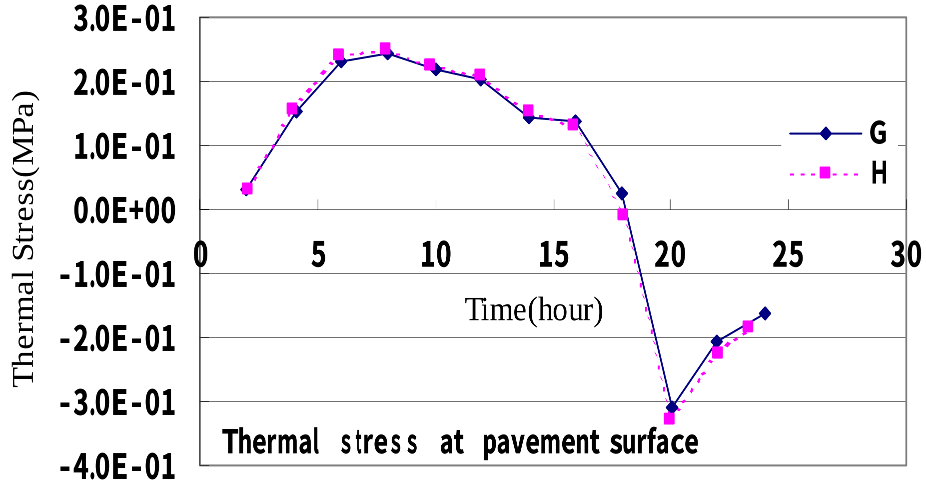

Figure 6 Termal stress in swiss

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