[Research Note]

New Wheel Tracking Test to Analyze Movements of Aggregates in Multi-layered Asphalt Specimens

El-Sayed Mohamed ABD-ALLA†1), Akihiro MORIYOSHI†2)*, Manfred N. PARTL†3), Kenzi TAKAHASHI†4), Takashi KONDO†5), and Takashi TOMOTO†2)

†1) Dept. of Civil Engineering, Faculty of Engineering, Assiut University, El-Gomhoria St., Assiut, EGYPT
†2) Dept. of Built-Environment Engineering, Faculty of Engineering, Hokkaido University, N13W8, Kita-ku, Sapporo 060-8628, JAPAN
†3) EMPA, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Überlandstrasse 129, CH-8600, SWITZERLAND
†4) Itogumi Construction Co., Ltd., N4W4-1, Chuo-ku, Sapporo 060-8554, JAPAN
†5) Dept. of Civil Engineering, Tomakomai National College of Technology, Nishikioka 443, Tomakomai, Hokkaido 059-1275, JAPAN

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This paper describes a new wheel tracking test for analyzing movements of aggregates in mixtures. The test device is conducted using as examples four-layered specimens taken from two Swiss national motorways, where severe rutting (G section) and longitudinal cracking (H section) were observed. This test method was developed by Moriyoshi. Tests can be carried out under temperature distributions similar to field situation.

Two-dimensional movements and strains between aggregates for four-layered specimens due to the moving wheel loads were analyzed by right angle for direction of wheel pass. For this purpose, the cross section of the slabs with a width of 30 cm was divided optically into 5 vertical subsections. The transverse permanent surface deformations, the area changes in the transversal subsections as well as the maximum deformation of the surface and layer-interface through the centerline of the applied wheel load were determined. Strain distributions between aggregates in mixtures at high temperature (45°C) under 600 passes were also measured by photo analysis.

Test results show consolidation of the asphalt mixtures and material flow on the surface near the wheel load. The results also demonstrate that the aggregates (size of aggregate: 2 mm or larger) in each mixture move mainly in vertical direction. Large strains (40% or larger) between aggregates at summer condition were measured in the surface mixture near wheel track after 600 passes.

Keywords

Asphaltic mixture, Permanent deformation, Strain distribution, High temperature, Wheel tracking test, Optical analysis

1. Introduction

Rutting deformation is one of the most severe deterioration phenomena of asphalt pavements in the world[1)~3)]. In order to study the rutting mechanism, a new wheel tracking machine was developed by Moriyoshi[4),5)].

SHRP (Strategic Highway Research Program) suggested that $G^*/\sin\Delta$ of the binder in the mix to be a main factor for assessing rutting susceptibility and specified the some values and requirements to reduce the risk of rutting. However, meanwhile, it was found by different researchers that these specified values for asphalt pavement cannot necessarily prevent rutting in all cases[6)]. This is particularly true of mixtures that were not included in the SHRP studies. Therefore, it became clear that rutting could not be taken into account accurately without considering and investigating the behavior and structural mechanism of the whole compacted mixture[7)]. In order to do this, a new machine was developed in order to analyze movement of aggregates as well as the strains between aggregates in the pavement layer under cyclic wheel loading. The machine allows producing an arbitrary temperature distribution in the cross section of the specimen and analyzing the movement of aggregates in multi-layered mixtures under wheel tracking test conditions by optical analysis[4)]. In this sense, the new device is different from existing rutting devices such as LCPC (Laboratorie Central des Ponts Chaussées) wheel tracking test.

The new Hokkaido Wheel Tracking Test (HWTT) was carried out on multi-layer slabs (G and H section, depth: 20-24 cm) taken from the Swiss national motorway (A-1) for a specified temperature distribution.

* To whom correspondence should be addressed.
* E-mail: moriyosi@eng.hokudai.ac.jp

2. Experiment

2. 1. New Wheel Tracking Test

The main concept of the new test device is the same as the conventional wheel tracking test developed by Transportation Research Laboratory (TRL) in the United Kingdom. The technical characteristics are as follows:

Wheel: Wheel diameter, 20 cm; Width of wheel, 5 cm; Solid tire, Dunlop hardness 80; Contact pressure, 55 N/cm^2

Specimen: 30 width × 30 length × 20.2 or 24.1 depth, cm.

Wheel tracking system: Rotating steel bed system, tracking speed, 42 pass/min.

Temperature of specimen: Surface 45°C; bottom of specimen 8°C or 10°C

Figure 1 presents a schematic overview of new wheel tracking test.

One transversal side of the steel frame holding the specimen is made of transparent glass in order to take photographs with a 35 mm camera, at each 100 passes of wheel, as shown in **Fig. 2**.

The wheel tracking effect on each specimen G and H was investigated after 0.5 h (1260 passes), 1 h (2520 passes), 1.5 h (3780 passes) and 2 h (5400 passes). The vertical temperature gradient in the specimen ranged from high temperature (45°C) at the surface to low temperature (8°C for G section and 10°C for H section) at bottom respectively. This temperature gradient simulates the "rutting" season (summer condition), *i.e.* March to November conditions, in Switzerland.

2. 2. Structure and Materials

Both pavements consisted of the following four asphalt concrete courses: wearing course (WC), binder course (BDC), upper base course (UBC), lower base course (LBC).

An overview on the material is given in **Tables 1** and **2**. AB means dense graded hot mix asphalt concrete; the number 16 denotes the nominal maximum aggregate size (in millimeters). The bituminous binders of slab G, are penetration graded ranging from B40/50 to B180/220. The wearing courses contain natural Trinidad Lake Asphalt, 1.25% by weight (M%). The layers of slab H contain tar-bitumen TB2000. Such pavements have no longer been used in Switzerland since many years ago for health reasons, of course, but were considered in this investigation as a reference because of extremely well performance in terms of

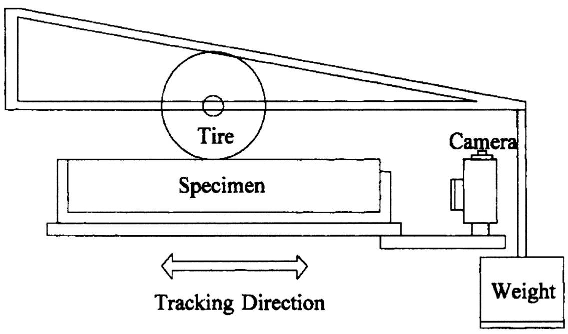


Fig. 1 Overview of Hokkaido Wheel Tracking Test (HWTT)

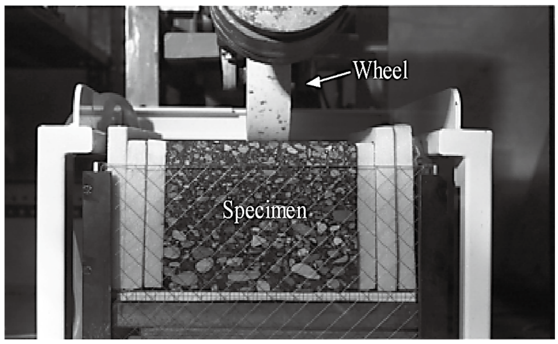


Fig. 2 Slab under Repeated Loading in the Hokkaido Wheel Tracking Test (HWTT)

Table 1 Material Characteristics and Sampling Data of WC, BDC, UBC and LBC Pavement Courses for Section G

Section G	WC (wearing course)	BDC (binder course)	UBC (upper base course)	LBC (lower base course)
Mix type	AB16	AB16	HMT32	HMT32
Binder type	B80/100	B80/100	B80/100	B80/100
Trinidad epure M%	1.25			
Maximum aggregate size [mm]	16	16	32	32
Binder content (recovered binder), M%	6.14	5.44	4.06	3.95
Air void content, V%	3.5	4.7	2.6	2.3
Voids mineral aggregate, VMA V%	17.9	17.5	12.3	12
Voids filled with asphalt cement, VFA V%	80.4	73.1	78.8	80.9
Thickness [mm]	30	43	77	91
Maximum deformation [mm]	6.2	5	3	3
Sampling time				
Service time @ sampling time [years]	6	6	6	6
ESALs/lane @ sampling time [millions]	6.1	6.1	6.1	6.1

Table 2 Material Characteristics and Sampling Data of WC, BDC, UBC and LBC Pavement Courses for Section H

Section H		WC (wearing course)	BDC (binder course)	UBC (upper base course)	LBC (lower base course)
Mix type		TA16	TA16	HMT32	HMT32
Binder type		TB2000	TB2000	TB2000	TB2000
Trinidad epure M%		1.25			
Maximum aggregate size	[mm]	16	16	32	32
Binder content (recovered binder), M%		5.64	5.3	4.24	3.82
Air void content, V%		2.6	4.8	3.7	3.9
Voids mineral aggregate, VMA V%		15.6	17.3	13.8	12.7
Voids filled with asphalt cement, VFA V%		83.3	72.2	73.2	69.4
Thickness	[mm]	37	31	53	81
Maximum deformation	[mm]	3.6	0.2	1.3	0.5
Sampling time					
Service time @ sampling time	[years]	6	6	6	6
ESALs/lane @ sampling time	[millions]	6.1	6.1	6.1	6.1

rutting and durability.

2. 3. Analytical Method

Surround of section of specimen through the glass on steel frame was cut by 1 cm scale in order to determine the *X*-*Y* coordinate. The analog photo of the cross section taken with the 35 mm Nikon camera, was transferred to a digital image by film scanner. This digital image was superposed to the initial image using a calibrated scale. Thereafter, movements and strains between aggregates were calculated by the Photoshop software. *X*-*Y* coordinate was measured by 0.1 mm wide scaling at intersection of major axis and edge of aggregate and the change of distance under wheel tracking test between those *X*-*Y* coordinate for every aggregate (2 mm or larger) were calculated. Thereafter, the strains of those distances in tension were calculated using original distance. The movements of the aggregates were calculated by 0.1 mm wide scaling. The degree of movement was expressed by deformation and strain between 0 pass and 600 passes (only for wearing course). The vertical deformations on the surface of layers G_1 and H_1 and at the layers interface (G_2, G_3, G_4 and H_2, H_3, H_4) through the centerline just below the wheel track were calculated considering the average movements of some aggregates near the interface (see **Fig. 3**).

The Photoshop software version 4 JP by Adobe Co. was used to identify the deformation states in the slabs after 0.5 h (1260 passes), 1 h (2520 passes), 1.5 h (3780 passes) and 2 h (5040 passes).

The area changes of the overall cross section with reference to the total cross section were calculated as a function of wheel passes. In addition, the area changes of several 5 cm wide subsections after different wheel passes were calculated using the initial area of the subsections and the volume of subsection at each stage. The change of the subsection areas was expressed as percentage of the initial areas.

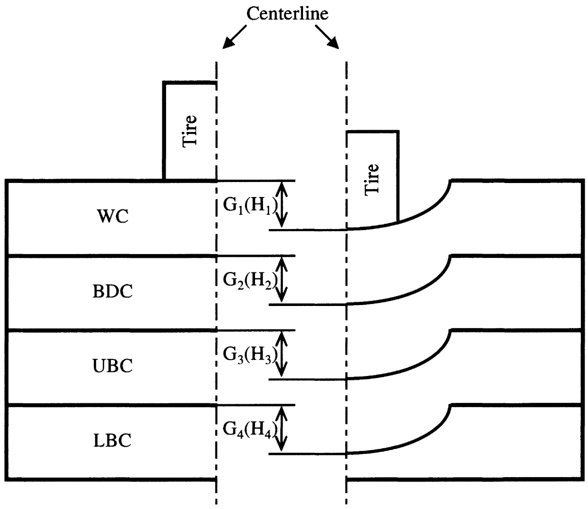


Fig. 3 The Vertical Deformations on the Surface of Layers

3. Results and Discussion

Figures 4 and **5** show the strain distribution between aggregates in the slabs at summer condition (surface temperature 45°C, bottom temperature 8°C for G section and 10°C for H section) after 600 wheel passes. Large strains in the wearing course of section G with severe rutting are located in lower region of the layer[8], whereas large strains in the wearing course of section H with longitudinal cracking are observed in the upper regions of the layer[9]. This means that cracking in section G occurs in the lower region of the wearing course and cracking in section H occurs in the upper region of the wearing course (see **Tables 1** and **2**).

Figures 6 and **7** show the vertical deformations on the surface and at the layers interface through the centerline just below the wheel track for section G and section H. The deformation decreases as a function of pavement depth due to spreading of pressure with increasing depth from the surface.

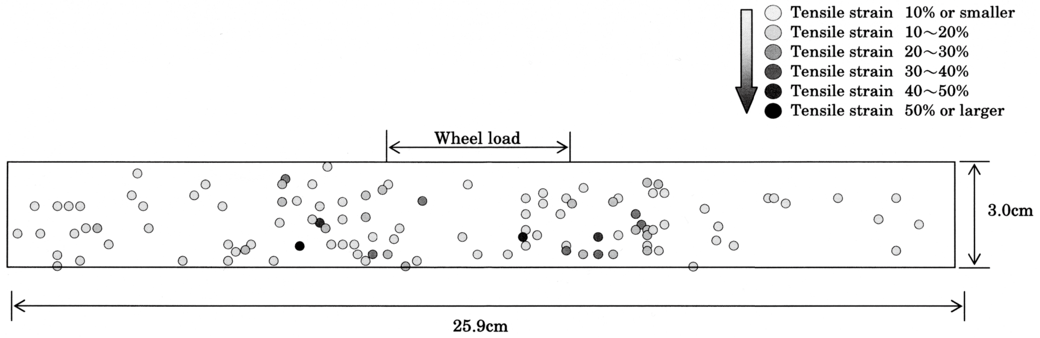


Fig. 4 Strain Distribution in the Wearing Course of Section G after 600 Wheel Passes

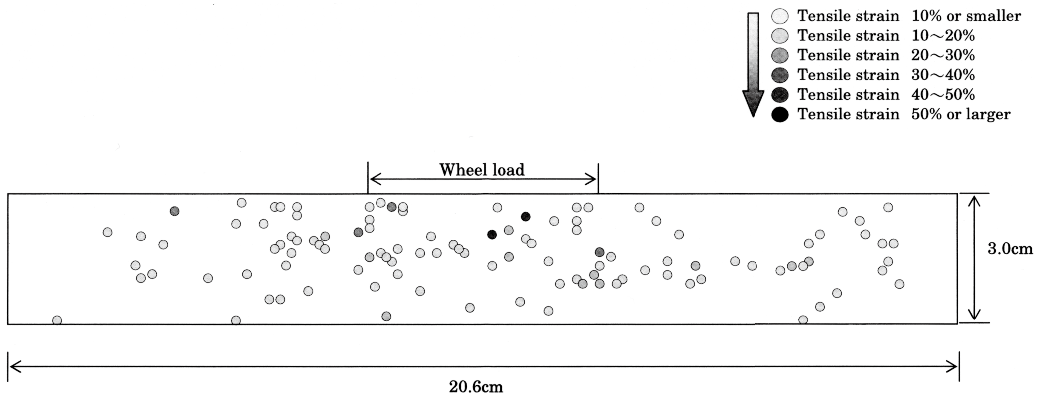


Fig. 5 Strain Distribution in the Wearing Course of Section H after 600 Wheel Passes

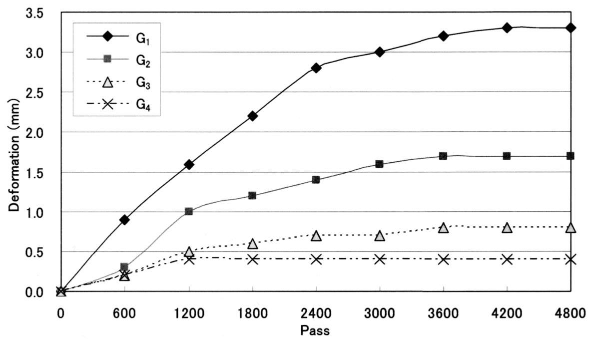


Fig. 6 Permanent Deformation on the Surface and the Layer Interfaces of Section G

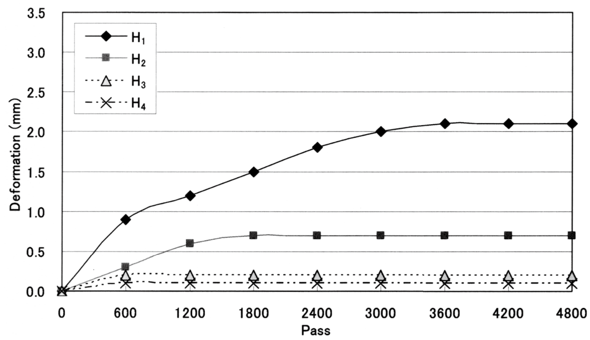
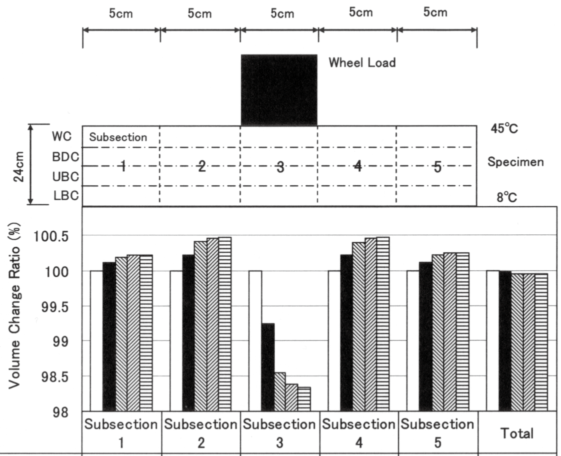


Fig. 7 Permanent Deformation on the Surface and the Layer Interfaces of Section H

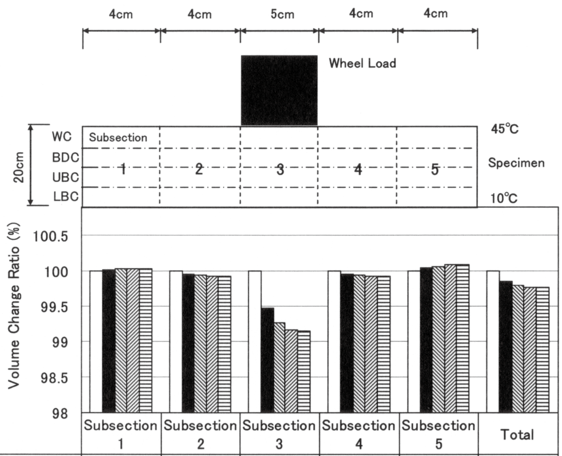
It can be noticed that the permanent deformations of the surface course for both sections are larger than in the deeper layer and increase with increasing wheel passes. However, the deformations decrease with increasing distance of the layer from the surface. The results of section H are similar to the findings of section G. On the other hand, it is obvious that the deformations of section H are 30% lower than those of section G. This may be attributed to the mechanical characteristics and composition of the mixtures. These findings are confirmed by the long term pavement performance (LTPP) behavior in the field where section G suffered from severe rutting whereas section H suffered from longitudinal cracking.

The area changes of the overall cross section of specimen G and several 5 cm wide subsections after different wheel passes are presented in **Fig. 8**. The middle part (subsection 3) represents the loading zone. The area of the middle part of the specimen decreases with increasing wheel passes and reaches 1.66% of the original area after 4800 passes. The area of the lateral subsections 2 and 4 increases with increasing wheel passes;



	Subsection 1	Subsection 2	Subsection 3	Subsection 4	Subsection 5	Total
□ 0pass	100.00	100.00	100.00	100.00	100.00	100.00
■ 1200pass	100.12	100.22	99.25	100.21	100.12	99.98
▧ 2400pass	100.20	100.41	98.55	100.40	100.22	99.96
▨ 3600pass	100.22	100.46	98.39	100.45	100.25	99.95
⊟ 4800pass	100.22	100.47	98.34	100.47	100.26	99.95

Fig. 8 Partial Area Change in the Asphalt Pavement Slab of Section G during Hokkaido Wheel Tracking Test (HWTT)



	Subsection 1	Subsection 2	Subsection 3	Subsection 4	Subsection 5	Total
□ 0pass	100.00	100.00	100.00	100.00	100.00	100.00
■ 1200pass	100.02	99.96	99.48	99.95	100.04	99.85
▧ 2400pass	100.03	99.94	99.27	99.94	100.06	99.79
▨ 3600pass	100.03	99.93	99.17	99.93	100.09	99.77
⊟ 4800pass	100.03	99.93	99.15	99.93	100.09	99.76

Fig. 9 Partial Area Change in the Asphalt Pavement Slab of Section H during Hokkaido Wheel Tracking Test (HWTT)

after excessive repeated loading, the area decreases more than the corresponding initial one. The area changes of subsections are nearly similar on both sides of the loading zone. Deviations of these lateral subsections for right and left may be attributed to the eccentricity of the wheel. It can also be observed that the total volume of specimen decreases as the number of wheel passes increases (**Fig. 8**).

The area changes of the section of specimen H and of several subsections similar to those of section G after different selected wheel passes are given in **Fig. 9**. The middle subsection 3, which represents the loading zone, and the lateral subsections 2 and 4 each have a width of 4 cm. However, the width of the other lateral subsections is different. The area of the subsection in the middle part of the specimen decreases with increasing load repetition by 0.85% after 4800 passes. The areas of the lateral subsections 1 and 5 gradually increase with increasing wheel passes. The area changes are not similar in the lateral subsections 1 and 5 due to the additional area from non-straight edges of specimen and the eccentricity of the wheel load. Furthermore, the total area of specimen decreases as the number of wheel passes increases. It means that surface deformation for both mixtures occurred due to consolidation rather than flow in the layers at summer condition under wheel tracking test.

Then, we found that this machine allows analyzing the movement of aggregate and strain between aggregates in the mixture and the area change of each vertical subsection of four-layered specimens at summer condition. It was also found that the surface deformation is mainly caused by consolidation of the mixture. For the particular slabs investigated in this study it was also shown that all four layers deformed due to the moving wheel load.

4. Conclusions

(1) The new Hokkaido Wheel Tracking Test (HWTT) allows measuring the permanent deformation at every depth in the cross section of a multi-layered specimen and enables to determine the area change of subsections in those specimens at every wheel passing stage.

(2) Surface deformations of both pavement sections investigated in this study are larger than those in the deeper layers, and all layers deform successively with increasing wheel passes.

(3) The area changes of the slabs of both pavement sections are not similar on the laterally to the loading zone (subsection 1, 5) and the total area of both specimens decreases with increasing number of wheel passes.

(4) Permanent surface deformation of both sections occurred due to consolidation rather than flow in mixture at high temperature (45°C) under the new wheel tracking test.

(5) Large strains (40% or more) between aggregates occurred in wearing course after 600 wheel passes at summer condition.

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要　　旨

新しいホイールトラッキング試験法による多層系アスファルト混合物の骨材挙動解析

El-Sayed Mohamed Abd-Alla[†1)]，森吉　昭博[†2)]，Manfred N. Partl[†3)]，
高橋　健二[†4)]，近藤　　崇[†5)]，東本　　崇[†2)]

[†1)] Dept. of Civil Engineering, Faculty of Engineering, Assiut University, El-Gomhoria St., Assiut, EGYPT
[†2)] 北海道大学大学院工学研究科環境創生工学専攻，060-8628 札幌市北区北13西8丁目
[†3)] EMPA, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Überlandstrasse 129, CH-8600, SWITZERLAND
[†4)] 伊藤組土建(株)，060-8554 札幌市中央区北4西4-1
[†5)] 苫小牧高等専門学校都市工学科，059-1275 北海道苫小牧市錦岡443

本研究はスイスの国道でわだち掘れのひどい区間（G区間）とこれに隣接した縦き裂のひどい区間（H区間）の各4層系のアスファルト混合物の内部の骨材の動きが解析できる新しいホイールトラッキング試験機について述べている。この試験装置は北海道大学で開発されたものであり，これは現場の舗装内部の温度分布と同様な状態で実験できる。この装置は4層系の混合物の内部の骨材の2次元的な動きやひずみが車輪と直角方向の写真撮影により解析可能である。本装置は混合物の断面（幅20～24 cm）を鉛直方向に五つに分割し，載荷荷重の中心線上での表面や境界層での最大変形量や，表面の横方向の変形量，垂直方向に五つに分割された部分の面積の変化や骨材間の混合物の内部のひずみ分布が測定できる。

実験結果より荷重付近での混合物表面での流動や混合物の圧密現象がこの装置で観察された。また，実験中に混合物内部の2 mm以上のすべての骨材が垂直方向に移動していること，高温で600回の車両通過だけで表層内部に局部的に40％以上の大きなひずみが生じることを明らかにした。