A Study on Structural Performance Deterioration Model for Pavement Asset Management

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Abstract

East, Central, and West NEXCO operate about 8,600km of toll expressways all over Japan. Since porous asphalt pavement became a standard surface course, more than 10years has passed and about 70％ of the roadway has been paved. Recently, underlying binder layer to be loosened under immersed condition due to the penetrated water is becoming one of major damages and cracking on conventional pavement is still major damage. The asset management becomes more important to maintain old and damaged pavement assets properly despite the limited budget and human resources. The exact evaluation of pavement condition and future deterioration forecasting are inevitable to realize pavement preservation and selection of proper maintenance methods. In this paper, following current status of surface characteristics of pavement on expressways, the structural diagnosis method and crack deterioration forecasting model based on the Markov probability model are described. The damage of striping inside the porous asphalt pavement and the traditional damage of cracking on the dense graded asphalt pavement can be detected by the deflection index. The deterioration forecasting model also seems to be applicable enough in the PMS. The new inspection and structural diagnosis method based on the study results will be also mentioned.

Keywords: Asset management, pavement structure, inspection, assessment, deterioration forecasting

1. Forward

Nippon Expressway Company Limited (NEXCO) East, Central, and West operate about 8,600km of toll expressways all over Japan. Since porous asphalt pavement became a standard surface course, more than 10years has passed and about 70％of the roadway has been paved to upgrade safety and comfortability. Recently, underlying binder layer to be loosened under immersed condition due to the penetrated water is becoming one of major damages which lead to the pumping phenomenon and partial deformation on the pavement (Shimeno 2009). The cracking on conventional pavement is still one of major damages. Shortage of experienced engineers and limitation of budget allocated to the maintenance works make the pavement preservation difficult.

The asset management becomes more important to keep pavement condition healthier effectively under the limited human and budget resources. The proper evaluation of pavement condition and the future performance prediction model in the asset management are vital for the pavement preservation and selection of maintenance methods.

In this paper, following current status of surface characteristics of pavement on expressways, the study deterioration forecasting model based on the Markov probability model are described. The new idea of inspection and structural diagnosis method due to the study results will be also mentioned.

2. Pavement asset management

2.1 Pavement asset management activities

The flow of pavement asset management is shown in **Figure1**. The activities of asset management include setting of maintenance level or target, searching asset condition by inspection, assessment of asset, planning maintenance, exercising maintenance, evaluation of project and these activities are blushed up through the PDCA cycle. In these activities, evaluation of current condition, future performance prediction, and selection of maintenance method based on the LCC analysis are

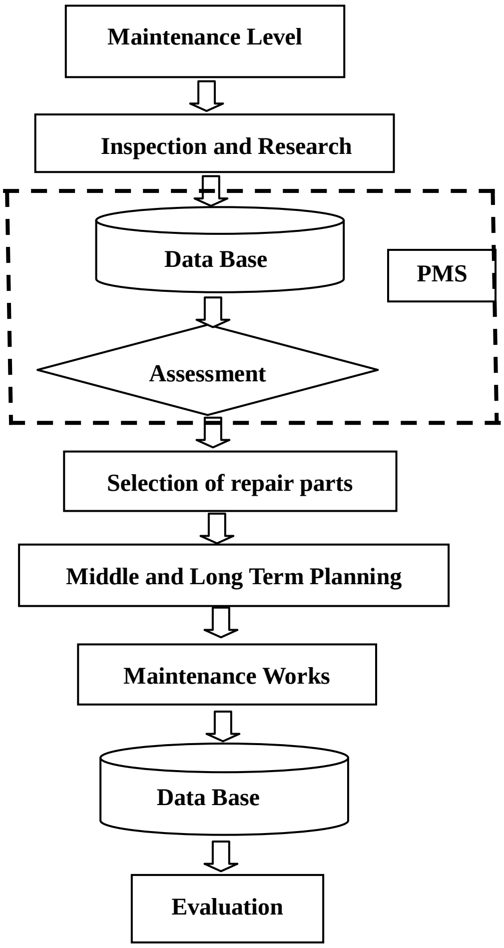


Figure1 Flow of pavement asset management

key factors and those are derived from analysis of compiled condition data (Shimeno 2009).

2.2 Inspection items of pavement maintenance

The inspection and survey of surface characteristics are inevitable to detect the condition of pavement assets and they are conducted almost periodically based on the traffic volume and so on. The items of the inspection are, a) rutting, b) cracking, c) evenness, d) faulting, and e) skid resistance. These items are measured by following NEXCO's standard manual (East, Central, West Nippon Expressway Company Limited 2006).

The rutting, cracking, and longitudinal profile are measured by measuring vehicles at 80km/h. Following the continuous measurement of rutting depth, the maximum depths of every 20m are picked up and the average depths of every 100m are calculated to record in the data base as the formal figure. The crack ratio is calculated based on the area of alligator crack, length of longitudinal and transverse crack, and area of patching. The evenness is evaluated by the IRI (International Roughness

Table1 Threshold values of pavement maintenance

Rutting (mm)	Faulting (mm)		Skid resistance (μV)	Evenness IRI (mm/m)	Crack ratio (%)
	Joint	Others			
25	20	30	0.25	3.5	20

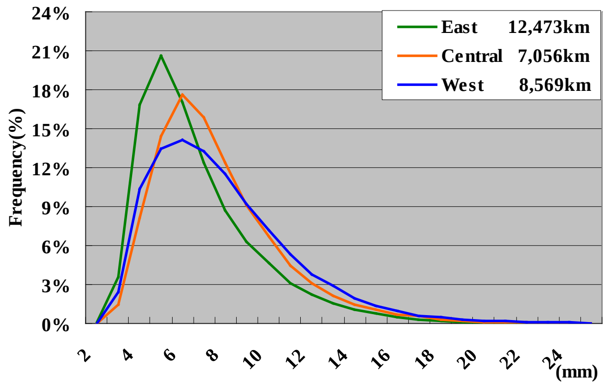


Figure2 Distribution of rutting depth

Index) which is derived from calculation of the measured profile data by the Quarter-Car model. The skid resistance is measured by the wheel locked type skid resistance vehicle at 80km/h spreading water to assure the water film of 0.5to 1.0mm of thickness. The skid resistance coefficient is calculated every 200m and recorded as the formal figure. The threshold figures of 5 items for maintenance are shown in **Table1**.

2.3 Current status of surface characteristics

Figure2 shows the distribution of rutting depth in each company. The flow rutting was dominant in early 1990 and intensive countermeasures were conducted. As the result, the average and maximum figures of rutting became small and the damage issue was improved drastically.

Figure3 shows the distribution of IRI for evenness. The most frequent figure appears around 1.5 and the riding comfort on expressways mainly belongs to fair to good based on the result of our research.

Figure4 shows the distribution of crack ratio. The crack ratio of porous asphalt pavement and rigid pavement is small and less than 5% mainly. The ratio of dense graded asphalt pavement becomes worth to 25% and more serious damage like more than 10% appears in some expressways. The pavement of

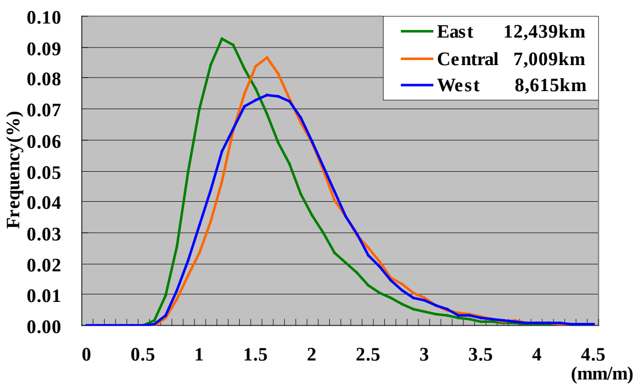


Figure3 Distribution of IRI

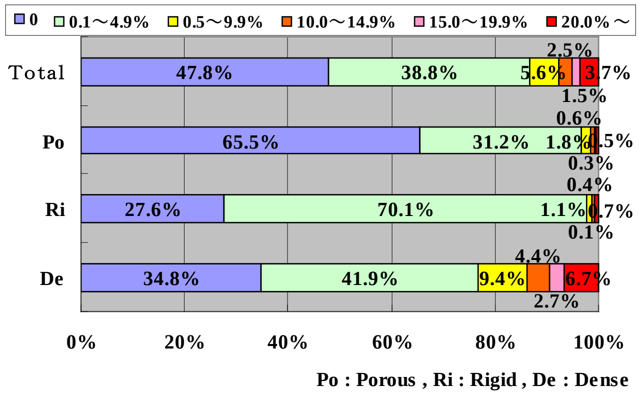


Figure4 Distribution of crack ratio

Picture1 Damage under porous asphalt

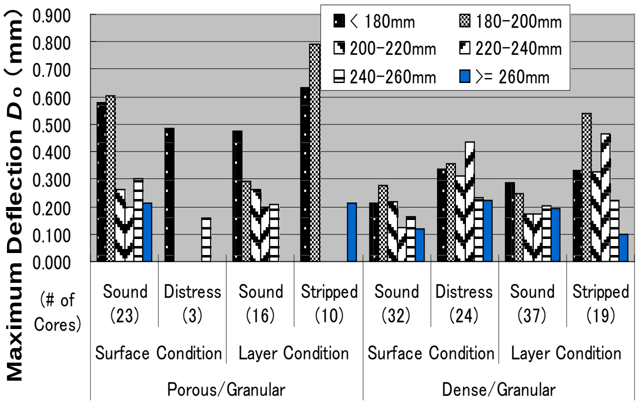


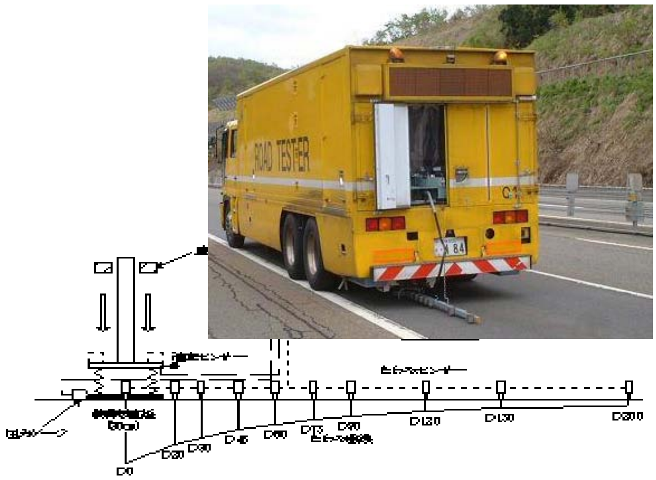
Figure5 Deflection and distress of pavement types

expressways with light to middle traffic volume tends to have more serious cracking and those cracks reach subbase sometime. The crack becomes one of the major damages to be coped with in our maintenance.

3. Structural evaluation of pavement damaged by cracks

Picture1 shows the condition of sampled core of porous asphalt pavement. In this survey section, there are no cracks on the pavement surface and the crack reaches subbase. Like this phenomenon, striping damage below the surface course has been observed in some expressways recently and early detection of such damage becomes very important to cost oriented maintenance.

Figure5 shows the relation among the maximum deflection, cracks, and striping of both porous asphalt pavement and dense graded asphalt pavement (Kamiya 2008). The deflection is measured by FWD (Falling Weight Deflectometer) shown in **Picture2**. The striping means that damage by the striping is observed in anywhere layers



Picture2 Deflection measurement by FWD

below surface course. The cracks on surface of porous asphalt pavement can be observed rarely and the D0 of pavement thickness with less than 200mm is significantly large compared with other pavement thickness categories. In case of dense graded asphalt pavement, pavements with both cracks on the surface and striping below the surface course have larger D0 simply. These facts indicate that the crack ratio is

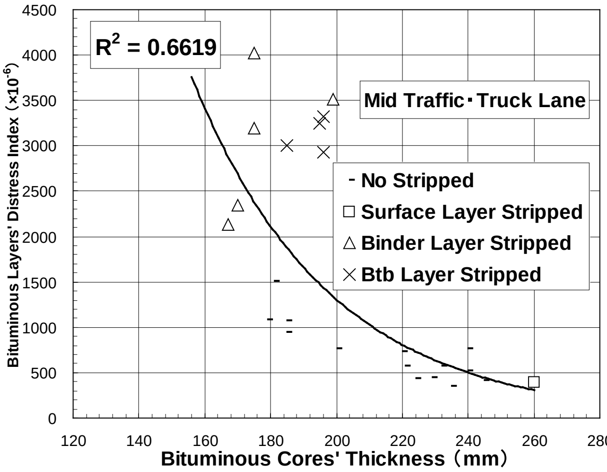


Figure6 Deflection index and damage of striping

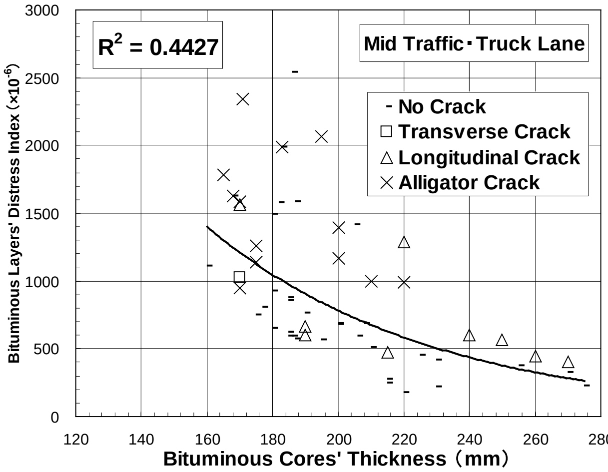


Figure7 Deflection index and damage of cracking

Table2 Damage rank of cracking

Damage rank	**Crack ratio(%)**
1	**Cr = 0**
2	**0 ≦ Cr < 2.5**
3	**2.5 ≦ Cr < 5**
4	**5 ≦ Cr < 10**
5	**10 ≦ Cr < 20**
6	**20 ≦ Cr**

not a good index to detect the structural damage of porous asphalt pavement and the deflection can be useful index to evaluate the inside striping.

From our experience, the difference between D0 and D90 (D0-D90) reflects pavement structural condition well and structural evaluation was made by analyze D0-D90 along with damage of sampled cores.

The D0-D90 divided by the design thickness which was defined as bituminous layer's distress index (deflection index) was used to evaluate structural damage to ease or discriminate the effect of pavement thickness to the deflection.

Figure6 shows the relation between the deflection index and striping of porous asphalt pavement with granular subbase and the index of each pavement thickness seems to have threshold figure between healthy and striping condition (Kamiya 2008). **Figure7** also shows the relation between the deflection index and some types of cracks on dense graded asphalt pavement with granular subbase and the index can also be the threshold to detect the damage of cracking (Kamiya 2008).

As the result, both the damage of striping inside the porous asphalt pavement and the traditional damage of cracking on the dense graded asphalt pavement can be detected in comparatively early stage of damage progress through the analysis of deflection index.

4. Performance forecasting model for cracking

The performance prediction model plays important role to plan proper maintenance methods and its costs in the asset management. The probabilistic deterioration forecasting model for a network level has been studied and a multi-stage exponential hazard model combining with the Markov transition probability was used to develop new forecasting model (Kumada 2009).

The data for this analysis to lead the forecasting model was collected from about 100km of monitoring spots on expressways all over Japan during 2006 to 2008. The damage rank for cracking was divided into 6 categories based on the threshold figure of 20% for maintenance as described in **Table2**. The variables for the analysis are type of pavement, type of road structure, and traffic volume. Some of the monitoring spots may be maintained during survey period which leads to the lack of transitional sampling data and affects the probabilistic model. Therefore, the bias against the lack of sampling data was considered in the probabilistic forecasting model.

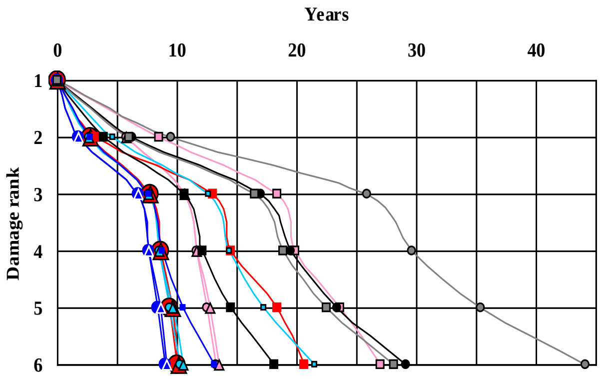


Figure8 Deterioration curves of cracks

The deterioration curves for cracking of every variables combination are shown in **Figure8** and the elapsed times to reach the final damage rank for every variables combination are also shown in **Table3**. As a whole, the variables combination affects the deterioration progress of cracking and the deterioration gets faster after exceeding rank 3. The progress of dense graded asphalt pavement is faster than that of the porous asphalt pavement. The progress of rigid pavement is slower than that of asphalt pavements.

These analysis result probes that the deterioration forecasting model seems to be applicable enough in our PMS judging from real maintenance experience.

5. New inspection and assessment method for pavement structural deterioration

The current pavement inspection consists of daily observation from patrol vehicle, following up survey for damage noticed spots, and periodic surface characteristics survey by measuring vehicles. The surface characteristics are standard items for the normal inspection and structural survey was conducted only when the crack ration is about to exceed the threshold figure of 20%. The FWD is used to measure the deflection in the survey and the condition of sampled cores is also observed to decide final decision of maintenance.

As mentioned earlier, the traditional damage of cracking on dense graded asphalt pavement is still major damage and the striping damage below the surface course has been observed in some spots of porous asphalt pavement recently contrary to the improvement of rutting. It is needed to establish

Table3 Elapsed time to final rank

No.	Combination of variobles			Years	legend
1	Porous	Earth	HTV	10.0	●
2,3			M・LTV	13.3	●
4		Bridge	HTV	10.2	▲
5,6			M・LTV	13.5	▲
7		Tunnel	HTV	20.6	■
8,9			M・LTV	26.9	■
10	Dense	Earth	HTV	9.0	●
11,12			M・LTV	10.2	●
13		Bridge	HTV	9.2	▲
14,15			M・LTV	10.5	▲
16		Tunnel	HTV	13.1	■
17,18			M・LTV	21.5	■
19,20	Rigid	Earth	H・MTV	29.2	●
21			LTV	44.2	●
22		Tunnel	HTV	18.1	■
23,24			M・LTV	28.1	■

HTV : Heavy Traffic Volume
MTV : Middle Traffic Volume
LTV : Light Traffic Volume

inspection and assessment method in order to detect structural damage in earlier stage considering the minimum LCC (Life Cycle Cost).

The deflection index is a key to assess the structural damage of pavement and it is desirable to survey the structural condition periodically. However, the measurement by FWD is still time and cost consuming and the traffic regulation is necessary to survey the deflection of pavement. The least and proper timing of survey by FWD is important in such situation.

In order to use FWD effectively to assess the structural damage and decide whether maintenance is required, the probabilistic deterioration forecasting model is vital to predict the deterioration progress of cracking and judge the proper timing of FWD survey. The process is as follows, a) to prepare the probabilistic forecasting models for both cracking and striping, b) to judge the proper timing of FWD survey based on observing the crack condition and forecasting the performance, and c) to decide proper timing of the survey by FWD. The inspection and assessment process to detect pavement structural damage is summarized in **Figure9**.

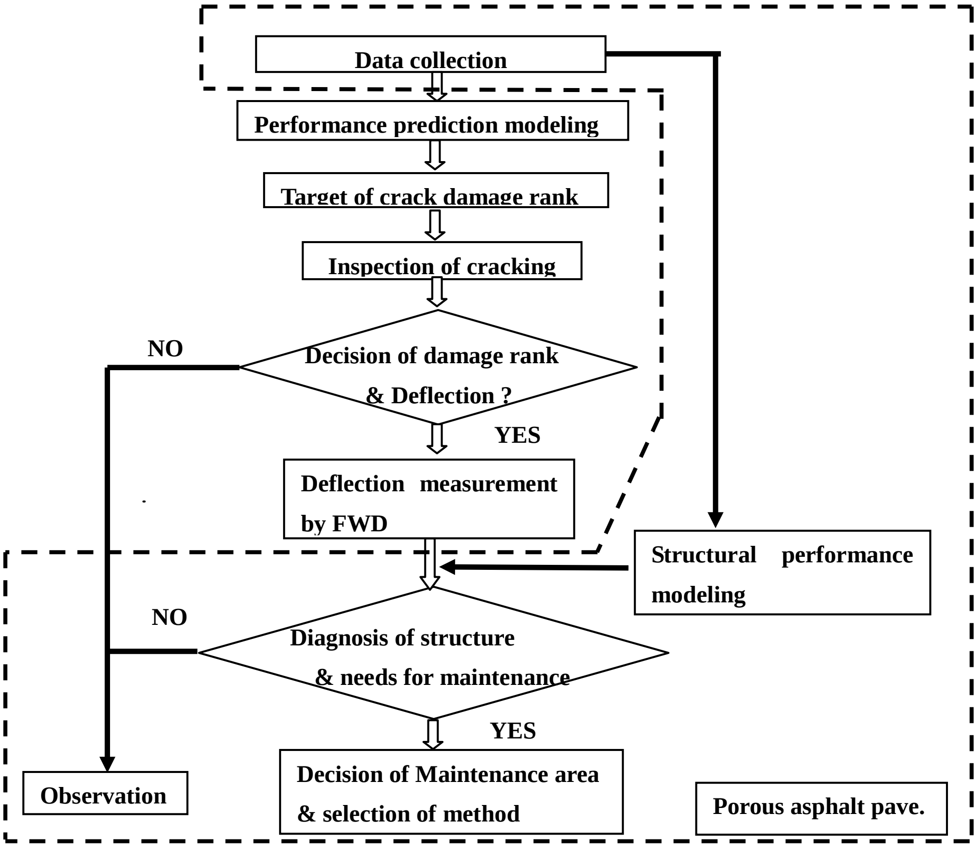


Figure9 Inspection and assessment process of pavement structure

In order to apply this method properly, the continuous data collection from monitoring spots and analysis are needed to have further study on relation between deterioration progress of cracking, striping and structural damage.

6. Conclusion

In this paper, the current status of surface characteristics on expressways was described and structural evaluation method and deterioration forecasting model for cracking were summarized.
The inspection and assessment method for pavement structural damage was also mentioned. Followings were made clear.

a) Traditional cracking on dense graded asphalt pavement is still major damage and the striping damage below the surface course has been observed in some porous asphalt pavements.
b) The damage of striping inside the porous asphalt pavement and the traditional damage of cracking on the dense graded asphalt pavement can be detected in comparatively early stage of damage progress through the analysis of deflection index and damage.
c) The probabilistic deterioration forecasting model seems to be applicable enough in the PMS.
d) New inspection and assessment method for pavement structure based on the forecasting model and structural evaluation by deflection index are expected to detect the structural damage in earlier stage.

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