# Study on How to Determine Repair Thickness of Damaged Layers for Porous Asphalt

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ABSTRACT: Porous asphalt has been widely used as standard road surface for the nationwide toll motorways under NEXCO. However it is difficult to appropriately estimate structural condition only from outlook of its road surface, unlike dense asphalt pavements. In fact unfamiliar distresses suddenly and intermittently take place in servicing several years, such as partial plastic flow and particles of binder layer mix blowing up from its porosity. Before getting into these final life stages of porous asphalt, an efficient and non-destructive method that can accurately evaluate structurally damaged layers has been strongly needed. Because the sample cores are often fractured, the assumption of multi-layered elastic theory seems difficult to apply. Therefore deflection basin parameter rather than back-calculated layer modulus was applied as structurally distress index in this study. In order to clarify the relation between the deflection basin parameter and bituminous layers' distress condition, cores were sampled from the FWD loading point and subjected to laboratory mechanistic tests. It was found that damaged and sound cores are distinguishable in a relation between bituminous cores' thickness and a deflection basin index ($D_0$-$D_{900}$) divided by cores thickness. Because it was also found that decrease of this index goes with the increase of each layer's mix strength, including resilient modulus and indirect tensile strength, it is speculated that the index can be used to appropriately determine repair thickness by setting mix criteria for identifying to replace with new materials. Finally the way of a repair design using the index is introduced.

KEY WORDS: Porous asphalt, structural distress, repair, deflection basin, laboratory tests

## 1 INTRODUCION

For upgrading safety on wet road surface, porous asphalt has been widely implemented in the Japanese nationwide toll motorways as standard road surface since 1998. Currently the pavement shares approximately 70% of the roadway being operated by three companies, namely East, Central and West Nippon Expressway Company, (hereafter called NEXCO). A few years after implementation, however, unfamiliar distress types of porous asphalt rather than dense graded pavement have been observed all over Japan.

Photo 1 shows partial plastic flow (left) and blowing up of particles of the binder layer's mix (right), which was weakened by rainfallwater, remained on the layer under wider ranges of temperature in Japan. Needless to say, this underlying layer based problem needs higher repair costs. However a much more annoying problem is that it is difficult to appropriately estimate the structural condition only from outlook of its road surface, before getting worse into the distresses that are the final life stages of porous asphalt, as shown in Photo 1.

This paper describes an efficient and non-destructive diagnosing method that can accurately evaluate structurally damaged layers for porous asphalt and help determine a repair thickness. Literature review was first commenced in order to investigate what structural distress indices have been studied worldwide.

Photo 1: Partial plastic flow (left) and blowing up of particles from porosity (right)

## 2 LITERATURE REVIEW

### 2.1 Back-calculated Layer Modulus

Most of the structural design methods that have been studied all over the world are based on a multi-layered elastic theory. The basic assumption of the theory is that each layer's material is homogenous and isotropic and that there is full friction between layers (Yoder and Witczak 1975). Currently available design methods of pavement including Mechanistic Empirical Pavement Design Guide published by AASHTO and Thickness Design Asphalt Pavements by Asphalt Institute are based on this assumption. Although those design methods are all applicable to dense graded asphalt pavements, they seem never to porous asphalt pavements. In other words there has been not much study worldwide on the structural distress mechanism of porous asphalts.

Photo 2: Sampled core from porous asphalt just before rehabilitation

Photo 2 shows a bituminous layer's core sampled from a section of porous asphalt just before rehabilitation. If the core is in laboratory, it should be regarded as fracture although not yet tested. Because the core condition is never fallen on the assumption of the multi-layered elastic theory, it is questionable to move on to calculating back-calculated layer modulus that is based on the theory. Further because this kind of core sampling is not a rare case for porous asphalt, it is judged that back calculated layer modulus not be used as structurally distress index for this study.

## 2.2 Deflection Basin Parameter

Another index to be applied for the index is a deflection basin parameter. This index has been studied since Dynaflect was used before FWD.

Table 1: Structural evaluation using deflection basin parameters (Horak, 2008)

| | Structural condition rating | Deflection bowl parameters | | | | |
|---|---|---|---|---|---|---|
| | | $D_0$ (μm) | RoC (m) | BLI (μm) | MLI (μm) | LLI (μm) |
| Granular base | Sound | <500 | >100 | <200 | <100 | <50 |
| | Warning | 500-750 | 50-100 | 200-400 | 100-200 | 50-100 |
| | Severe | >750 | <50 | >400 | >200 | >100 |
| Cementitious base | Sound | <200 | >150 | <100 | <50 | <40 |
| | Warning | 200-400 | 80-150 | 100-300 | 50-100 | 40-80 |
| | Severe | >400 | <80 | >300 | >100 | >80 |
| Bituminous base | Sound | <400 | >250 | <200 | <100 | <50 |
| | Warning | 400-600 | 100-250 | 200-400 | 100-150 | 50-80 |
| | Severe | >600 | <100 | >400 | >150 | >80 |
| **Note:** These criteria can be adjusted to improve sensitivity of benchmarking. | | | | | | |

Table 1 is an example of use of the parameters for structural evaluation in South Africa (Horak, 2008). The parameters indicate the structural condition rating for base types. However the rating cannot objectively tell the condition of structural distress. Although there are some more others showing the possibility of use of the sorts of parameters (Kim, 2001; Aavik et al. 2008; Al-Qadi et al. 2003; Yildirim et al. 2006; Gopalakrishnan, 2008; Zhang et al. 2003), they are not objectively explaining the relation between structural distress condition and the parameters.

Therefore in order to clarify the relation between the distress condition and the deflection basin parameter, cores are to be sampled from the FWD loading point and to be subjected to mechanistic tests, including resilient modulus and indirect tensile tests for each layer mix.

# 3 STRUCTURAL DISTRESS SURVEY

## 3.1 Target Deflection Basin

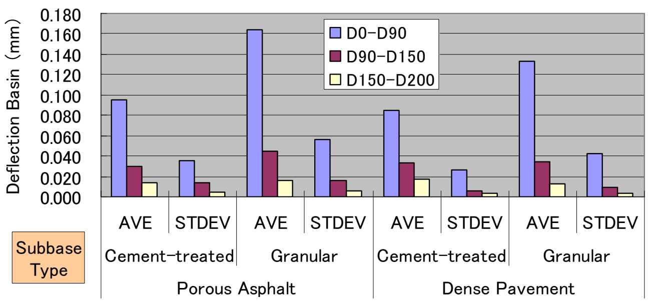


Figure 1: Average and standard deviation of deflection basin data (10,000 measurements)

Figure 1 summarizes average and standard deviation for deflection basin parameters from over 10,000 FWD measurements of the motorway sections being planned for rehabilitation. Average and standard deviation levels of deflection basin $D_0$-$D_{90}$ are varying much among the surface and subbase layer types, while those are showing almost the same levels respectively for $D_{90}$-$D_{150}$ and $D_{150}$-$D_{200}$. Since the data points cover nationwide motorways, it was judged appropriate that $D_0$-$D_{90}$ be set for the target deflection basin.

Generally only bituminous layers including surface, binder and bituminous-treated base layers have been rehabilitated for repair projects in NEXCO. Therefore the relation between deflection basin and structural strength of bituminous layers will be discussed as follows.

### 3.2 Deflection Basin and Structural Strength

In Japan it is reported that deflection basin $D_0$-$D_{200}$ correlates to the structural strength of bituminous layers (Abe et al. 1993). In overseas countries it is reportedly $D_0$-$D_{300}$ correlates to the strength (Crovetti, 2009), and $D_0$-$D_{600}$ does in case bituminous layers are thick (Houben et al. 1999).

Figure 2 depicts deflection curves using GAMES (JSCE, 2004) by providing 50cm thick pavement layers with different levels of moduli in simulation of FWD measurements on a motorway section. It is obvious that the deflection curves are obtained separately for the levels of subbase layer's modulus. Also the effect of changing of bituminous layer's modulus (structural strength) is going to be remarkably separated at basin 900mm or nearer to the loading point.

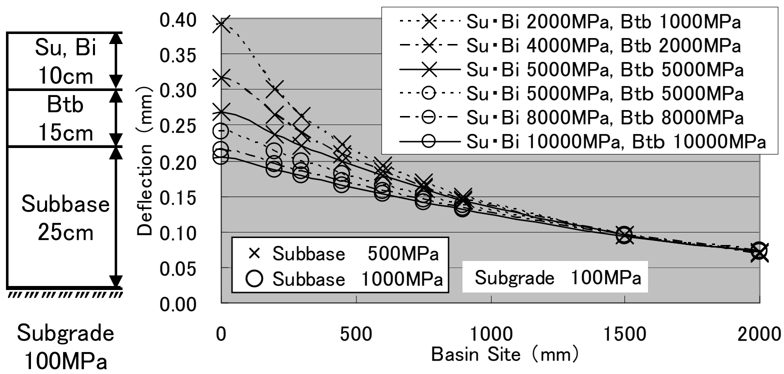


Figure 2: Deflection curves using GAMES in simulation of FWD measurements

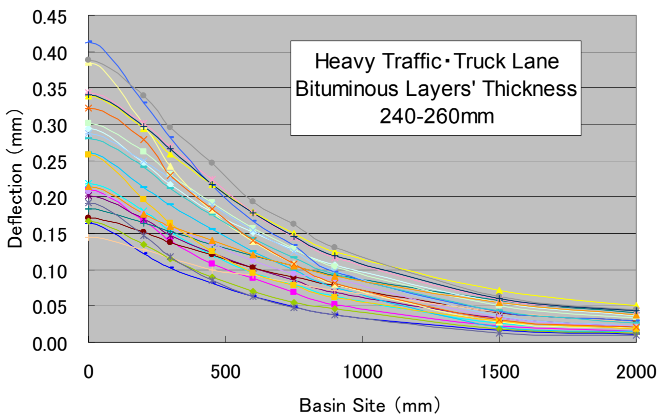


Figure 3: Deflection curves (corrected at 20°C) from a real motorway section with porous asphalt having granular subbase layer

In order to compare with Figure 2, Figure 3 with the same bituminous layer thickness is obtained from a real motorway section with porous asphalt, being planned for rehabilitation. Because of actual pavements structurally damaged, deflection curves in Figure 3 vary more than those in Figure 2. Although there seems to be a changing point in curvature at basin 750-900mm in Figure 3, not such point at 200-300mm in both Figure 2 and Figure 3. This is considered because thickness of bituminous layers for a Japanese motorway is prescribed 180mm or thicker, while the relation between $D_0$-$D_{200}$ and structural strength of bituminous layers was found in Japanese ordinary road sections with bituminous layers mostly less than 200mm thick (Abe et al. 1993).

Therefore it was judged in this study that deflection basin $D_0$-$D_{900}$ correlates to structural strength of bituminous layers.

# 4 STRUCTURAL DISTRESS INDEX

## 4.1 Development of Index

Figure 4 shows a relation between deflection basin $D_0$-$D_{900}$ and bituminous cores' thickness for porous asphalt having granular subbase layer. Visual observations of cores are also put into the figure. Naturally there is a tendency of decreasing the basin $D_0$-$D_{900}$ as with the increase of cores thickness. More importantly visually damaged cores tend to be plotted upward for cores thickness; sound cores are plotted downward, while problematic ones upward. Therefore this could be a repair chart for being able to distinguish the levels of bituminous layers' condition.

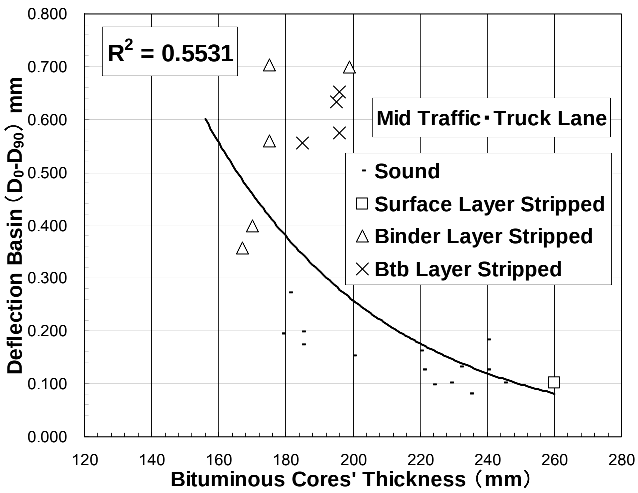


Figure 4: Deflection basin $D_0$-$D_{900}$ (corrected at 20°C) and bituminous cores' thickness for porous asphalt having granular subbase layer

Figure 5 replaces only deflection basin $D_0$-$D_{900}$ in Figure 4 with the same $D_0$-$D_{900}$ divided by cores thickness. The objective of switching this index is to intensify the correlation of $D_0$-$D_{900}$ to cores thickness. Accordingly there is a higher correlation ($R^2$=0.553) in Figure 5 than that ($R^2$=0.662) in Figure 4. If a core data is plotted upward even in Figure 5 with the higher correlation to cores thickness, the data is meant to show a higher relation to distress.

Because the new index ($D_0$-$D_{900}$ / cores thickness) is considered to mean unit of structural distress of bituminous layers, it is defined as bituminous layers' distress index in this study.

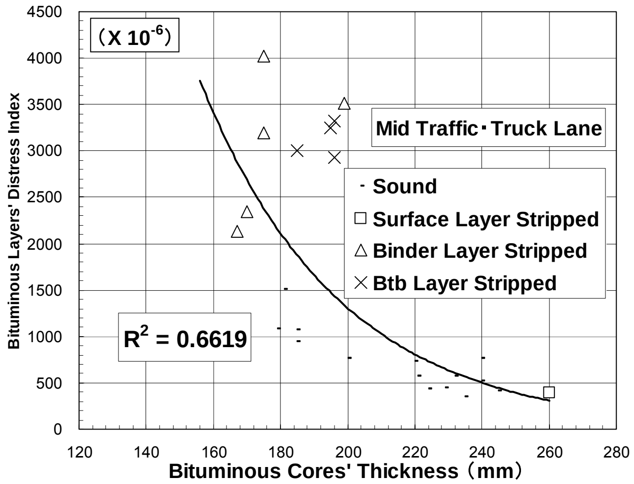


Figure 5: Structural distress index ($D_0$-$D_{900}$ / cores thickness) and bituminous cores' thickness for porous asphalt having granular subbase layer

4.2 Distress Index and Mix Strength

Because visual observation of sampled cores lacks objectivity in structural evaluation, it is still difficult to appropriately determine repair thickness or which layers to repair from Figure 5. In order to objectively evaluate the cores condition, sampled cores were cut and subjected to the following laboratory mix tests for each layer as shown in Table 1.

Table 1: Laboratory mix tests of bituminous cores cut for each layer for a section

| Test Method | Objective | Cores Designation | | |
|---|---|---|---|---|
| Density | Estimation of Air Voids | ○ | ○ | ○ |
| Maximum Gravity | | — | — | ○ |
| Resilient Modulus | Correlation to FWD Structural Distress Index | ○ | ○ | — |
| Indirect Tensile Strength | | ○ | — | — |
| Accelerated Water Pressure (60°C) | Providing Further Damage to Cores | — | ○ | — |
| Resilient Modulus after AWP | Correlation to FWD Structural Distress Index after Accelerated Water Pressure | — | ○ | — |
| Stripping Strength after AWP | | — | ○ | — |

Because of too much damaged condition, some cores were broken in sampling. In other cases where higher bituminous layers' distress index had been observed at the time of FWD measurement, some were incapable of resilient modulus and others showed decrease of indirect tensile strength after accelerated water pressure at 60°C (Motomatsu et al. 2004).

In order to develop a way of determining repair thickness, the followings are set for the two critical conditions for identifying to replace with new materials, to the cores after accelerated water pressure at 60°C.

#1 Incapable of resilient modulus due to cracking or deformation found in cores
#2 Indirect tensile strength less than average subtracted by 1σ (standard deviation)

Figure 6 shows bituminous layers' distress index and cores' thickness together with the conditions of resilient modulus and indirect tensile strength for porous asphalt having granular subbase layer. Mark "X" in the explanatory note indicates that a core is fallen on the above #1 or #2, which means necessity to replace the layer of the core with new materials. Round mark "○" indicates replacement of all bituminous layers including surface, binder and bituminous treated base layers. Triangle "Δ"and square "□" respectively indicates replacement of surface and binder layers and only that of surface layer.

In spite of not much data plots, each replacement group (○, Δ, □) tends to be positioned in the order of three layers replacement to one layer replacement, as with the decrease of distress index. This deeply means that decrease of bituminous layers' structural strength goes with the decrease of each layer's mix strength. Therefore it is speculated that the bituminous layers' distress index can be used to appropriately determine repair thickness.

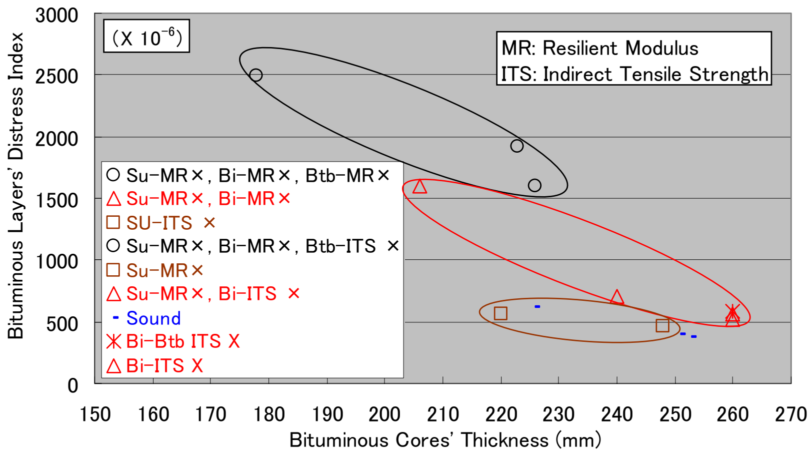


Figure 6: Bituminous layers' distress index and conditions of resilient modulus and indirect tensile strength for porous asphalt having granular subbase layer

Figure 7 shows indirect tensile strength of binder mix and its air voids. Because binder layer is most likely to be damaged due to immersed condition, its strength tends to be decreased as expectedly, as with the increase of its air voids. Although remained here, unrealistic air void levels less than 1.0% are due to errors of maximum density test.

Judging from a red arrow pointing around 3% that comes from the above critical condition #2 (Average -1σ = 0.7MPa), the importance of compacting binder layer in the field well to the around 3% level is suggested here.

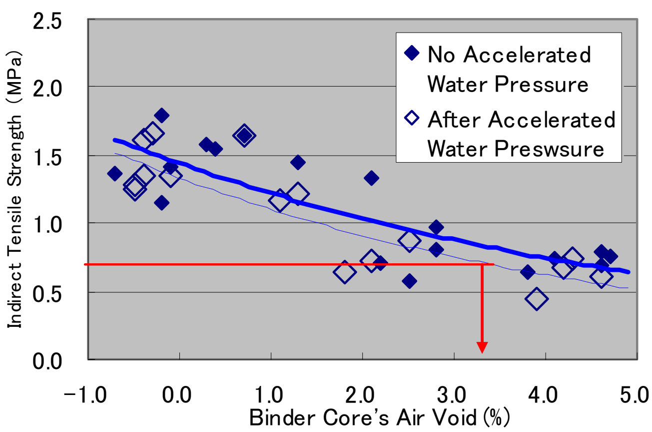


Figure 7: Indirect tensile strength of binder mix and its air voids, sampled from porous asphalt having granular subbase layer

## 5 REPAIR DESIGN

It is important to understand that a repair design is to improve or decrease higher deflection levels due to structural distresses into lower levels, by appropriately replacing problematic layers with new or sound layers. In designing a repair thickness, bituminous layers' distress index as part of repair design index can be used together with resilient modulus and indirect tensile strength as follows.

### 5.1 Resilient Modulus

Figure 8 shows a relation between bituminous layers' distress index and sum of each core's resilient modulus (MR) multiplied by its thickness. Very much importantly the former tends to decrease as the latter increases for each replacement group (○, Δ) like in Figure 6. This tendency implies an effectiveness of switching to new materials with higher MR or overlaying some more thickness. One more importantly, repair design can be made by setting a level of bituminous layers' distress index, for example 1000 x $10^{-6}$ as a design target or a sound level. Each arrow for each replacement group (○, Δ) can get to each summation level. If the current structural condition is put at red round (●), the required summation level will be 700,000 MPa•mm. This is a specified performance condition for being able to decrease deflection in terms of the distress index by approximately 1000 x $10^{-6}$.

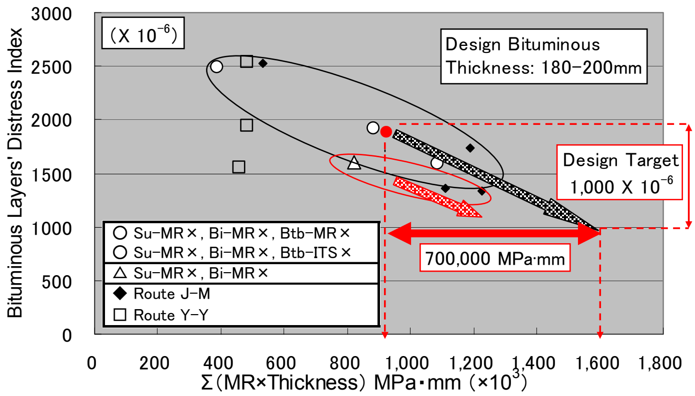


Figure 8: Distress index and summation (core's MR x thickness)

### 5.2 Indirect tensile Strength

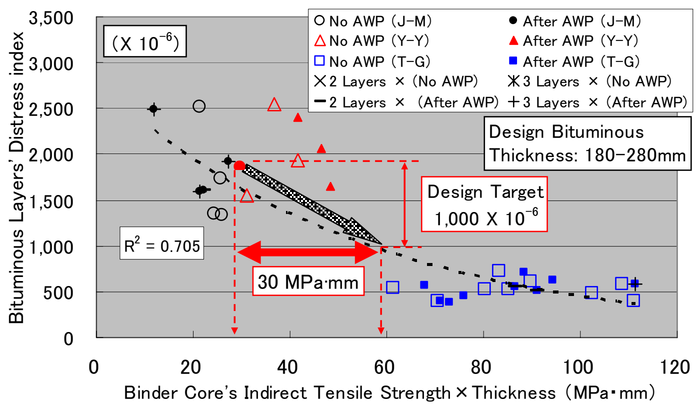


Figure 9: Distress index and binder core's indirect tensile strength x thickness

Figure 9 examines applicability of binder core's indirect tensile strength as a specified performance condition. Because of a high correlation between bituminous layers' distress index and binder core's indirect tensile strength multiplied by its thickness, binder layer is considered to greatly affect the durability of entire bituminous layers. Repair design can also be made by setting a level of bituminous layers' distress index, for example 1000 x $10^{-6}$ as a design target. An arrow can get to a summation level. If the current structural condition is put at red round (●), the required summation level will be 30 MPa•mm as a specified initial performance condition.

## 6 COCLUSION

For the purpose of developing an efficient and non-destructive diagnosing method that can accurately evaluate structurally damaged layers for porous asphalt and help determine a repair thickness, literature review, nationwide FWD measurements under NEXCO and extensive laboratory tests were conducted. The findings were summarized as follows.

1. Because fractured conditions are found in cores sampled from porous asphalt sections just before rehabilitation, back-calculated layer modulus that is based on a multi-layered elastic theory cannot be used as structurally distress index for this study. Instead deflection basin parameter is judged to be used.
2. In order to clarify the relation between distress condition and deflection basin parameter, it was revealed from literature review that cores are to be sampled from the FWD loading point and to be subjected to laboratory mechanistic tests.
3. According to nationwide FWD measurements of the motorway sections being planned for rehabilitation, it was judged appropriate that $D_0$-$D_{90}$ be set for the target deflection basin for this study.
4. In order to understand the relation between deflection basin and structural strength of bituminous layers, deflection curves using GAMES in simulation of FWD measurements and those obtained from a real motorway section being planned for rehabilitation were compared. Because of the similar tendency between them, it was judged that deflection basin $D_0$-$D_{900}$ correlates to structural strength of bituminous layers.
5. For the purpose of development of structural distress index for appropriately representing condition of bituminous layers, relations between the basin $D_0$-$D_{900}$ and bituminous cores' thickness together with visual observation of the cores were studied. Finally it was found that problematic cores are distinguishable in a relation between structural distress index ($D_0$-$D_{900}$ / cores thickness) and bituminous cores' thickness.
6. In order to develop a way of objectively determining repair thickness, the followings were set for the critical conditions for identifying to replace with new materials, to the cores after accelerated water pressure at 60°C. Because decrease of bituminous layers' structural strength goes with the decrease of each layer's mix strength, it is speculated that the bituminous layers' distress index can be used to appropriately determine repair thickness.
   #1 Incapable of resilient modulus due to cracking or deformation found in cores
   #2 Indirect tensile strength less than average subtracted by 1σ (standard deviation)
7. The condition #2 suggested the importance of compacting binder layer in the field well to its air void level of around 3%.
8. Finally the way of a repair design using bituminous layers' distress index was introduced. In a relation between bituminous layers' distress index and sum of each core's resilient modulus multiplied by its thickness, a specified performance condition can be obtained if a level of bituminous layers' distress index is set as a design target. This is also true in

another relation between the distress index and binder core's indirect tensile strength.

The bituminous layers' distress index, newly proposed in this paper is based on the use of deflection basin parameter that is a traditional way of structural evaluation. Because this new index is easily obtained once deflection can be corrected in terms of reference temperature (20°C in this paper), it can be implemented for practical use. For this purpose, further validation study is needed by examining the relation between the index and laboratory mechanistic tests of the field cores and finally by setting criteria for which layers to replace with new materials.

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