한국도로학회 논문집
第6券3號 2004年 9月
pp. 47 ~ 54

도로-포장시스템의 오염원 및 주변환경적 요인과의 상호작용

Interaction of a road-pavement system with pollution sources and environments

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요 지

도로-포장시스템의 성능은 구성재료 및 기계적 물리화학적 하중에 대한 재료의 민감도에 매우 관련이 깊다. 그러나 지금까지 오염원 침투에 따른 도로-포장시스템의 물리적 화학적인 영향에 대한 연구가 깊이 있게 다루어지지 않았다. 이에 대한 연구를 위해 본 논문에서는 도로-포장시스템과 오염원 및 주변환경적 요인과의 상호작용에 대한 고찰이 선행적으로 다루어졌다. 도로-포장시스템으로 오염원은 1) 포장표면으로 직접 침투하거나, 2) 도로 경계 면으로 침투하거나, 3) 물리적-화학적-생물학적 변화에 의한 흙 사이로의 간접 침투로 이루어진다. 오염원침투가능성은 재료종류, 입자크기, 기후 및 지질학적 특성에 관련이 깊다. 도로-포장시스템의 안정성 및 성능 또한 오염원 침투에 의해 영향을 받는다. 이와 같은 특성들을 고려할 때 도로 설계, 시공 및 유지보수와 관련된 일을 하는 공학자들은 이 문제를 심각하게 고려하여야 할 것이다.

핵심용어 : 도로, 포장, 오염원, 침투, 안정성

Abstract

The performance of road-pavement system is closely related to the constituent materials and their susceptibility to mechanical as well as physicochemical stresses. However, the influence of physical and chemical effects on the road-pavement system due to pollution intrusion has not been investigated fully. To study this topic, thus, the interaction of a road-pavement system with pollution sources and environments are identified and discussed preliminarily in this paper. Pollution intrusion to road-pavement system occurs by three basic mechanisms; 1) direct intrusion into pavement surface, 2) intrusion from the Right of way, and 3) physical-chemical-biological alterations. Pollution intrusion potential is closely related to material type, particle size, and climatological and topographical features. Stability and performance of road-pavement system is also directly affected by pollution intrusion. Based on these features, thus, engineers working in related to the road design, construction, and maintenance should be seriously considered this topic.

Keywords : road, pavement, pollution, intrusion, stability

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1. INTRODUCTION

Road-pavement is a layered system, the components include wearing surface, base, subbase and subgrade soil. The surface consists of portland cement concrete, asphalt or composites. The base and subbase include crushed stone, sand gravel or stabilized materials. Traffic loads are delivered from the wearing surface through the base and subbase materials to the subgrade. This load transfer is accomplished according to the frictional and cohesive characteristics of the underlying materials. These characteristics are known to be subject to changes in response to temperature, moisture, chemical composition and constituent mineralogy (Fang, 1993; 1997). There is a general appreciation for the influence of temperature and moisture conditions on pavement performance (Watson 1994). However, the extent to which these variables give rise to multi-media and coupled phenomena, which relate the flow of moisture, heat, electricity and pollutants to one another, has not received much attention. Moreover, while extensive work has been devoted toward understanding physical and chemical interactions in natural soils, (e.g., forces of attraction and repulsion, double layer theory, soil fabric, etc.), the significance in highway pavement systems is less clear.

Thus, several factors relating to road-pavement system are critically reviewed and discussed in this paper, including: (1) identification and characterization of pollution, (2) pollution intrusion mechanisms to pavement system, (3) factors affecting pollution intrusion potential, (4) estimation of pollution intrusion through pavement components, and (5) the performance/stability of road-pavement system.

2. IDENTIFICATION AND CHARACTERIZATION OF POLLUTION

For design, construction and maintenance of a roadway, the techniques for identification and characterization of ground soil and pavement components at the site(s) are among the prerequisites necessary to a more complete understanding of the soil-pollutant interaction in the environment. Typically, visual identification and characterization of roadway sites for either newly proposed or existing roadways is the same regardless of whether or not the site is contaminated. However, if the site is contaminated by natural or man-made, then further investigations are required. Procedures include visual identification, characterization and classification of contaminated soil for engineering use are summarized in Table 1.

Table 1. Visual identification and characterization of roadway (From Fang, 1993)

[1] Reconnaissance and Field Investigations: (a) Characteristics of site(s) included topographic and stratigraphic, (b) Ground soil/water characteristics, and (c) River/stream conditions.
[2] Color of Ground Soil and Water in River/Stream: (a) Color of ground soil such as: oily, shiny, and (b) Color of water and water bubbles such as white clean or yellow dirty.
[3] Odor of Ground Soil and Water
[4] Cracking Patterns of Ground Soil Surface, and
[5] Characteristics of Site(s): (a) Dead/dying and degree of decomposition of trees, shrubs, vegetation, birds, animals, etc., (b) Conditions of roads in surrounding areas, and (c) Degree of corrosion in surrounding facilities.

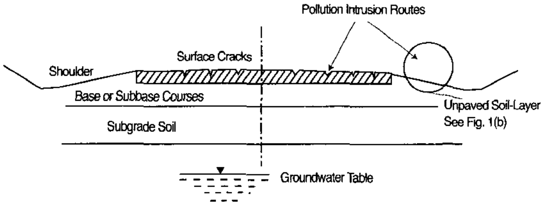
3. POLLUTION INTRUSION MECHANICSM TO HIGHWAY SYSTEM

Most types of pollutants are in liquid form. Regardless of the pollution sources and possible intrusion routes (Figures 1(a) and 1(b)), there are three basic mechanisms by which the soil-pavement system can be contaminated.

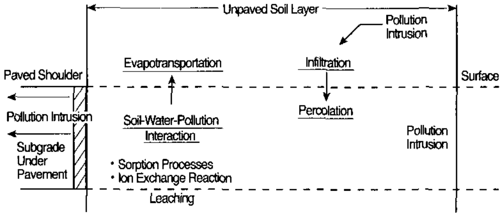
(1) Direct Intrusion from Pavement Surface: Contamination may occur from acid rain/snow; or oil or chemical wastes spilled on the pavement surface.

(2) Intrusion From the Right-of-way: Occurs when pollutants are introduced as leakage from well disposal or construction of waste disposal facilities such as landfill, septic tanks.

(3) Indirect Causes: Results from physical-chemical-biological alterations which allow polluting substances to move within or between soil layers. In this case, the phenomena covers decomposition process, sorption process, chemical alterations and bacteria attack, leaching and ion exchange reaction.



(a) Pollution intrusion through pavement surface



(b) Soil-water-environment interaction on unpaved soil behavior

Figure 1. Pollution intrusion routes and characteristics in a typical highway section with the right-of-way

4. POLLUTION INTRUSION POTENTIAL

4. 1 Material Types and Particle Sizes

Highway components consist of pavement wearing surface, base, subbase and subgrade embankment soil. The engineering characteristics of each material are significantly different. Also pollution intrusion potential hinges on the material' s particle size. The smaller particle sizes have larger surface area per volume, and more chance for interaction with the environment. Therefore, embankment soil is more sensitive to pollution intrusion than crushed stone base or sand-gravel subbase materials. This provides insight to the requirement that base material be non-plastic and have no greater than 7% fines (Garber and Hoel, 1997).

Unpaved shoulder material or embankment soil both often include fine-grained soil. Figure 2 shows the material types and sizes relating to the pollution potential based on Fang and Mikroudis' s work developed in 1989 (Fang, 1997). The pollution potential is reflected by pollution sensitivity index, (PSI). This index is a dimensionless number which is based on the assumption that the smaller the soil particle size, the larger the specific surface per volume and the greater the chance for soil interacting with the environment. The fine-grained soils

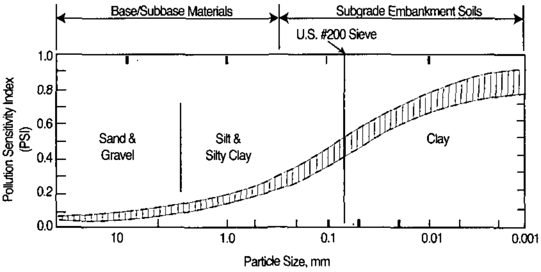


Figure 2. Material types and sizes relating to pollution potential as reflected by pollution sensitivity index (PSI) of base, subbase and embankment soil

are significantly influenced by pollutions due to their large specific areas. The flocculation type is the face to edge structure, which has large voids between soil particles and subject to pollution attack more than dispersive structure. The soil structure of clay can change from flocculation into dispersive arrangement or *vice versa* if certain environmental factors change caused by pollution intrusion and weathering. Figure 3 presents a similar trend indicating that the percent of clay passing #200 U.S. standard sieve relates to the material' s strength, permeability, frost penetration together with pollution potential. In examining Figure 3, as the increase if the percent of clay pass #200 sieve, in general the strength obtained from both confined or unconfined conditions increases, the permeability decreases due to the decreasing void space in soil mass, and the pollution potential increases due to the increasing the specific surface area. Since pollution potential is mainly based on particle size and surface areas, it is not related to permeability, which is based on void or porosity of space.

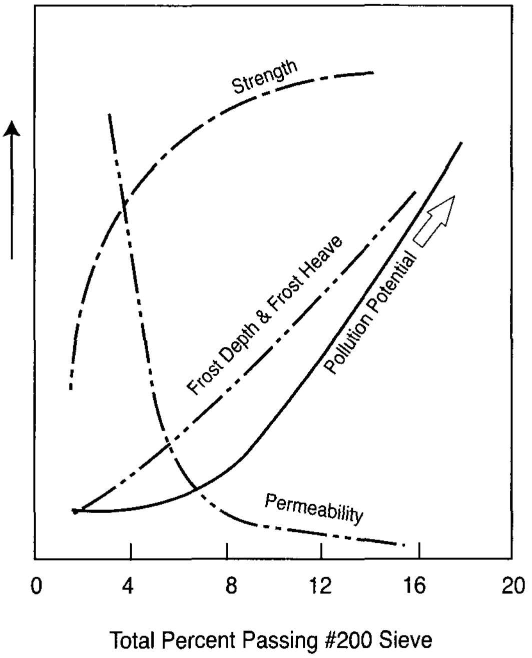


Figure 3. Percent of material passing #200 sieve relating to strength, permeability, frost penetration and pollution potential of embankment soil

4.2 Climatological and Topographical Factors

Climatological and topographical factors are major design features which influence the overall road-pavement system and also can influence the characteristics of pollution intrusion patterns and potentials and indirectly will influence the stability and performance of road systems. Table 2 summarizes climatological and topographical factors effects on pollution intrusion into road -pavement system.

The topographical features are important to the road-pavement systems (Figures1a, 1b and Table 2). Both surface and subsurface drainage patterns affect the pollution intrusion routes. Proper drainage systems must be provided to accomplish to move rain water in soil mass. All surface drainage must be away from roadway structures and subsurface drainage such as horizontal drains provided to remove water within the soil mass. Both climatological and topographical features will influence the characteristics of pollution intrusion patterns

Table 2. Climatological and topographical factors effects on polluted intrusion into road-pavement system

[1] Climatological Factors: (a) El Nino, La Nina effects: Cause abnormal weather, torrential rain, flash flood, (b) Wind: Controlling the direction of acid rain (or snow), and (c) Rainstorm: Causes flood, swelling, triggers the pavement shoulder slope failure, (d) Hot-cold, Dry-wet, Freeze-thaw Cycles: Causes shrinkage, volume change, cracking, subsidence and piping action of soil-pavement system.
[2] Topographical Factors: (a) Surface and subsurface drainage patterns, (b) Vegetation/tree types and patterns, (c) Geometric features of roadway and Right-of-way.

and will affect the stability or performance of foundation structures.

5. POLLUTION INTRUSION THROUGH PAVEMENT COMPONENTS

In general, most pollutants are in a liquid form. The liquid movement processes from ground surface and within the road-pavement system. Infiltration is the passage of liquid or water through the ground surface into the subsurface soil layer. The infiltration normally begins at a high rate and decreases to a minimum. From a highway design viewpoint, pollution intrusion is from pavement surface, and/or unpaved soil layer. The approximate estimation of these intrusions is presented as follows:

5.1 Portland Cement Concrete (PCC) Pavement

Based on the work done by Ridgeway (1976), a modified formula is proposed which considers the liquid pollution intrusion into soil-pavement system through Portland cement concrete (PCC) pavement surface joints such as construction and/or expansion joints. Amount of infiltration can be estimated from Equation [1] as:

$$Q = f_c[N + 1 + (W/s)] \qquad [1]$$

where Q = amount of infiltration(m³/hr/linear m of pavement), (L^3/hr/L)

f_c = coefficient of infiltration

= 0.1 for Portland cement concrete pavement surface,

= 0.2 for compacted dense base material,

N = number of lanes,

W = pavement width (m), (L)

s = PCC slab length (m), (L)

Coefficient of Infiltration, f_c, of water (non-polluted pore fluid) is recommended by Ridgeway (1976). For polluted pore fluid, the rate of infiltration changes. The infiltration rate of various types of liquids can be estimated based on the infiltration rate of water as reflected by the viscosity and the temperature of the liquid or polluted pore liquid. The viscosity of any liquid or their combinations can be determined by ASTM Standards (ASTM D445).

5.2 Portland Cement Concrete (PCC) and Asphalt Pavements

In addition, based on Moulton's (1991) work, a modified formula for estimation of infiltration rate considered with polluted liquid waste for both concrete and asphalt pavements as well as base courses can be estimated from a modified formula, Equation [2] presented as follows:

$$q_i = [I_c(N_c / W + W_c / WC_s) + k_p] \qquad [2]$$

where

q_i = design infiltration rate, (m^3/day/m^2 of drainage layer)
= correction of pollution intrusion. See Equation [1],
L_c = crack infiltration rate, (m^3/day/m^2 of crack),
N_c = number of contributing longitudinal joints or cracks on either rigid or flexible pavements,
W_c = length of the contributing transverse cracks or joints (m),
W = width of aggregate base or subbase subjected to infiltration (m),
C_s = spacing of transverse cracks or joints (m),
k_p = rate of infiltration (equal to the coefficient of permeability) through the uncracked pavement surface (m^3/day/m^2).

5.3 Pollution Intrusion Through Unpaved Soil Layers

If unpaved soil layers have cracks, the thickness of the saturated zone caused by liquid pollution can be estimated from Equation [3]. Equation [3] is developed based on the previous work done by Beattie and Chau (1976).

$$h = [\lambda][\xi]\frac{kt}{(S_f - S_o)n} \qquad [3]$$

where h = thickness of the saturated zone,

$[\lambda]$ = correction for surface cracks, this value varies from 1.05 to 1.15 depending on types of cracks as indicated in Table 3

$[\xi]$ = correction for polluted pore fluid,

k = coefficient of permeability, (cm/s),

t = duration of rain fall,

S_f = final degree of saturation,

S_o = initial degree of saturation,

n = porosity of ground soil.

Table 3. Values for correction of ground surface cracks (From Fang, 1997)

Types of Cracks	Correction Factors, λ
Hair Cracks	1.05
Alligator Cracks	1.10
Gully Cracks*	1.15

- Type of cracks for PCC pavement.
- For asphalt pavement, the severe wheel path rut also examined.

6. POLLUTION EFFECTS ON THE PERORMANCE/STABILITY OF ROAD-PAVEMENT SYSTEM

6. 1 Performance of Road-Pavement System

Cracking phenomena in a road-pavement system include: pavement surface, shoulders, the right-of-way as well as embankment soil. Cracking phenomenon is caused by energy imbalance due to pollution intrusion, internal moisture, temperature or non-uniform compaction effort during construction. Pavement surface cracking is also due to weathering, hot-cold, wet-dry, freeze-thaw cycles, and piping action on subbase as well as dynamic vibration due to moving vehicles. Pavement cracking during first cycle of wet-dry, freeze-thaw is much more critical than in second or third cycles, because during the first cycle the soil has higher moisture content and lower density.

Shrinkage, swelling and volume change of subgrade soil will affect the overall stability of the soil-pavement system as reflected on cracking patterns. Liquid pollutant effects on the coefficient of compressibility, c_v, as reflected on dielectric constant is shown in Figure 4. As dielectric constant increases so does the coefficient of compressibility, coefficient of permeability, and volume change. This means that polluted soil has more compressibility, settlement and low bearing capacity. These phenomena will reflect on the prefailure of pavement useful life (Fang, 1997).

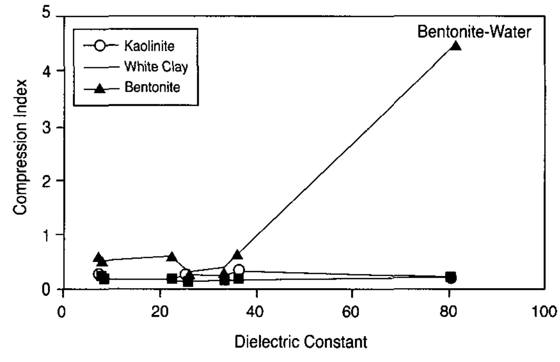


Figure 4. Effect of pollution on compressibility of some soils and clay mineral as reflected by dielectric constant

6.2 Stability of Roadway

Contamination will accelerate the progressive erosion or failures on highway shoulder and unpaved soil layer, because the pollutants tend to enhance ion exchange and reduction-oxidation reactions, acceleration of bacterial activities will loosen up individual soil particles and lead to progressive erosion and creep.

Slope stability problems at the high-fill along the embankment also are affected by pollution intrusion. Slope failure will directly affect the shoulder stability and consequently affect the stability of the roadway.

Pavement surface rut depth is defined as the permanent deformation along the out/in wheel paths due to moving vehicles. Rut depth is also referred to as pavement surface subsidence and is related to the compressibility and strength of embankment soil and pavement shoulder design.

Icing salt (NaCl) is frequently used during winter season on pavement. The icing salt effects on pavement surface, shoulders as well as roadside areas including roadside vegetation.

Sinkhole(s) appear along a highway route frequently in karst regions. These sinkholes will affect infrastructural characteristics of entire soil-pavement systems. This major feature in the karst region landscape has been shaped by the removal of calcium (Ca) and magnesium (Mg) as bicarbonates(HCO_3) from rock deposits ranging in composition from pure limestone through dolomite limestone to dolomite, the double salt of calcium pollution pore fluid in both acid rain and snow. Acid drainage and industrial wastewater, leaching from nearby sanitary landfill will greatly affect the sinkholes. Studies on how contaminated groundwater affects sinkholes made by Perlow et al. (1984) on Lehigh Valley, Pennsylvania deal with the phenomena.

7. SUMMARY AND CONCLUSIONS

(1) The interaction of a road-pavement system with pollution sources and environments are identified and discussed.

(2) The mechanism of pollution intrusion into the road-pavement is proposed. Pollution intrusion to road system occurs by three basic mechanisms; 1) direct intrusion into pavement surface, 2) intrusion from the Right of way, and 3) physical-chemical-biological alterations.

(3) The factors affecting the pollution intrusion potential include material types, particle size, conductivity characteristics, and pollutant types. Geometry of roadway design, climatic conditions, topographical features, as well as surface and subsurface drainage patterns also affect pollution intrusion potential.

(4) The estimation of infiltration of pollution through pavement surface, base, subbase and unpaved soil layer is presented. Three equations are proposed for estimating infiltration rate of polluted liquids into road-pavement systems.

(5) Since the polluted soil has more compressibility, settlement and low bearing capacity and the pollutants tend to enhance ion exchange and reduction-oxidation reactions, acceleration of bacterial activities, the stability and performance of road-pavement system is directly affected by pollution intrusion.

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ACKNOWLEDGEMENTS

This paper was supported by WonkwangUniversity in 2003.

〈접수 : 2004. 4. 14〉