Investigating the Need for Drainage Layers in Flexible Pavements

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INTRODUCTION

o Water can easily find its way into the pavement. Moisture accompanied by traffic loads and freezing temperatures can have detrimental effects on flexible pavement performance.

o A properly designed, constructed, and maintained subsurface drainage system can facilitate the immediate removal of any moisture that may have infiltrated the pavement structure, thereby acting to reduce pavement distresses such as fatigue cracking and rutting.

o Improperly designed or poorly constructed drainage systems, or those not properly maintained can often trap moisture inside the pavement structure thereby accelerating pavement damage, sometimes even more so than if no drainage system had been constructed.

o The longer moisture remains in the pavement structure, the more likely pavement failure will occur.

o The objective of this research is to evaluate the effectiveness of subsurface drainage for flexible pavements.

o Seepage analysis in the pavement can be useful to evaluate the effectiveness of subsurface drainage.

SOURCES OF WATER

o Water can infiltrate into the asphalt pavement through various sources: Surface infiltration, rising groundwater, seepage from higher ground, capillary action and vapor movement.

o Surface infiltration is the largest source of water which penetrates through cracks into the pavement.
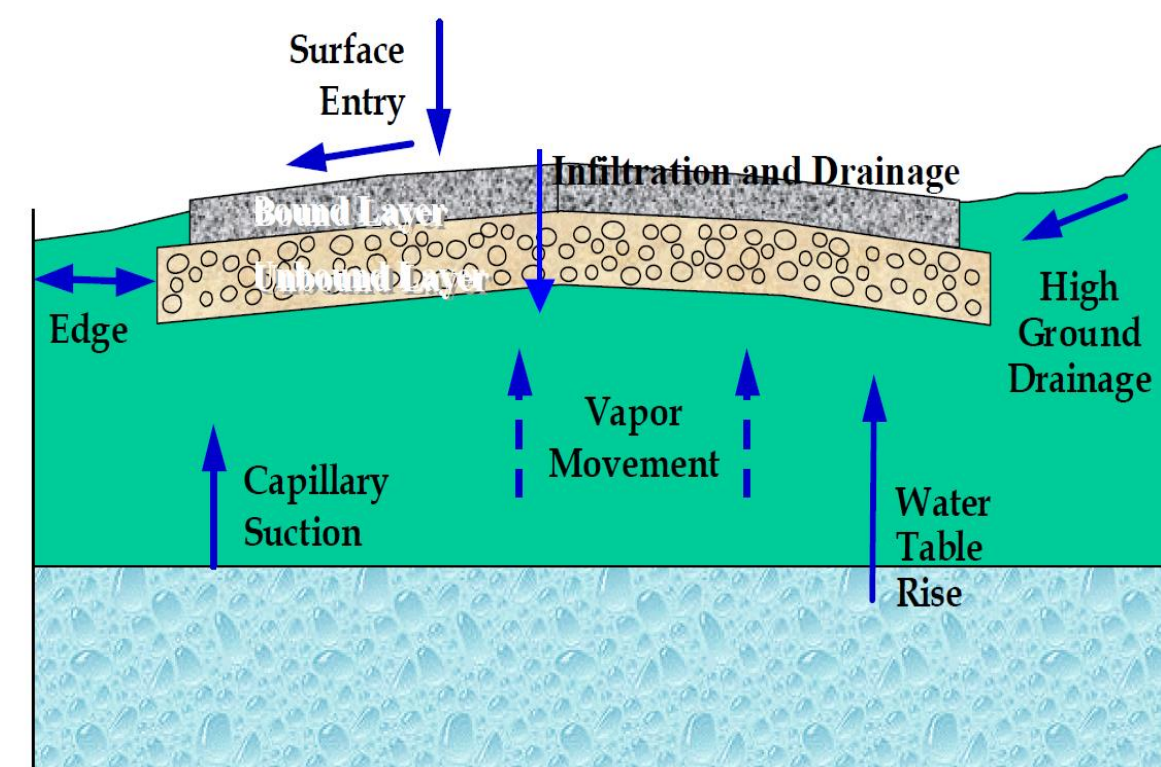

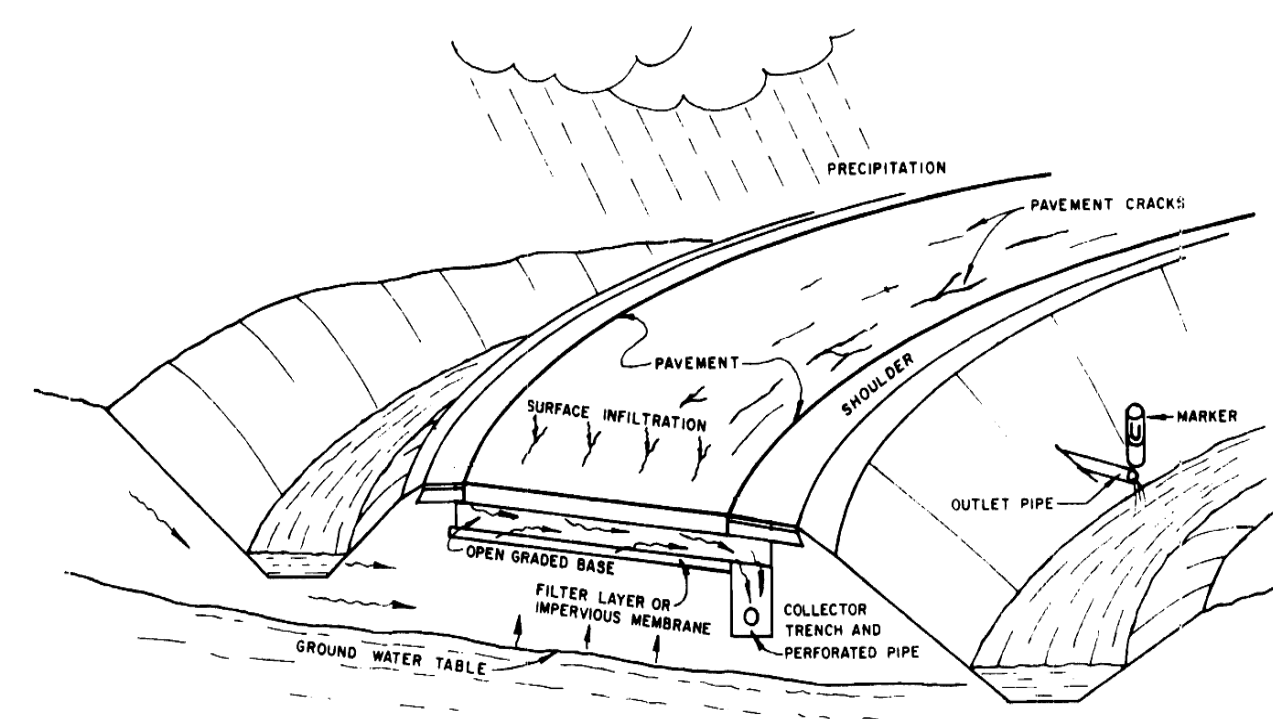**Figure 1-1 Sources of water that may infiltrate asphalt pavements (Apul, 2002)**

Figure 1-2 Surface infiltration into asphalt pavement with drainage system (Cedergren, 1972)

PAVEMENT DRAINAGE PERFORMANCE AND EFFECTIVENESS

o The effectiveness of a drainage layer is usually evaluated based on the time required for water to drain. The faster a pavement drains, the more effective the drainage layer.

o The FHWA developed the DRIP (Drainage Requirement in Pavement) software for design and analysis of pavement subsurface drainage. DRIP analyzes the water flow inside the pavement on the basis of the time-to-drain approach by considering the variation of hydraulic conductivity for the drainage layer (base) as well as dimensions of the pavement section.

o The AASHTO 1993 pavement design guide rates the quality of the drainage layer (permeable base) based on the time-to-drain approach (50% drainage), resulting in values from "excellent" to "very poor."

o A typical INDOT asphalt pavement section with incorporated drainage layer is used in the DRIP analysis (Figure 1-3). A pavement section with fixed geometry is modeled and the effects of drainage layer with different material properties investigated.

o The drainage layer is 10 cm thick and 8 m wide (permeable base). The permeable base cross-slope is specified as 2 percent. The drainage quality of the different materials was determined using a constant infiltration rate, 0.50 units, and a 1.4-inch per hour rain event. Table 1-1 shows the saturated hydraulic conductivity of different base materials and the results from DRIP based on time-to-drain approach with 50% drainage.
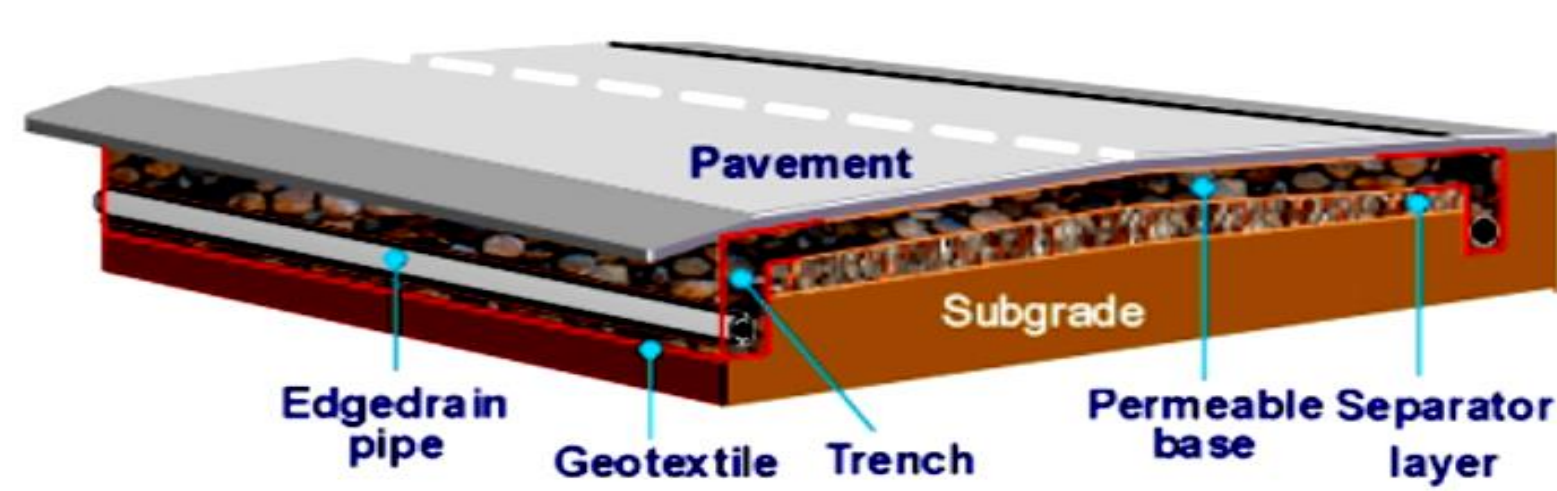

Figure 1- 3 Typical asphalt pavement section with drainage layer in DRIP program

DRIP RESULTS:

Table 1-1. Results from DRIP

Base Material	Lab Hydraulic Conductivity (m/day)	Porosity (VWC at fully saturation condition)	Quality of drainage (Time to Drain) 50% Drainage-hours
*HMA base #5C	102.7	0.164	2.75 - Good
*HMA base #2	13.8	0.05	6.15 - Good
*INDOT #8	1019	0.57	0.94 - Excellent
**HMA base 25mm	0.964	0.15-0.45	(264 to 791 - Poor)
**C & S PCCP	305	0.15-0.45	(0.83 - Excellent), (2.5 Good)
***Cement Stabilized	7724	0.15-0.45	(0.03, 0.1) - Excellent
***Asphalt Stabilized	7638	0.15-0.45	(00.03, 0.1) - Excellent
***AASHTO #57	8095	0.24	0.05 - Excellent

* Data from Hassan, 1996
**Data from Ji, 2015, Porosities are unknown (range is specified)
*** Data from Liang, 2010

o Results show excellent qualitative performance (Good, Excellent) of the pavement drainage layer for most base materials, except the dense-graded 25 mm asphalt base. This means they can drain 50 percent of drainable water within a maximum approximately of 6 hours (most do so in less than two hours).

o DRIP considers the pavement fully saturated with the constant hydraulic conductivity for drainable base. This is useful for quickly estimating a pavement section that will always remain below the ground water table (steady state condition), but it should not be used for unsaturated or partially saturated pavement. However, in the case of an unsaturated flow condition, while DRIP will to analyze the model, it considers the pavement to be in a saturated flow state. This causes an over estimated flow quantity because DRIP assumes the same rate of flux for both unsaturated and saturated section.

o Studies have indicated that Finite Element Methods (FEM) can be a helpful tool in analyzing seepage analysis of either saturated or unsaturated pavement sections (Ji 2013, Rabab 2007, Hassan 1996). Recent studies recommended unsaturated flow (seepage) principles be considered in the analysis of pavement subsurface drainage (Rabab 2007). This also requires precise consideration of the boundary and initial conditions as well as material hydraulic properties, including water retention curves and the hydraulic conductivity functions.

o General 2D flow equation : $\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t}$

For the Transient condition : $\frac{\partial h}{\partial x} = i_x$, $\frac{\partial h}{\partial y} = i_y$, k_x and k_y hydraulic conductivity in X and Y direction

θ = Volumetric Water Content (WVC)

$\frac{\partial \theta}{\partial t}$ gives the rate of the change of water stored in the material

FINITE ELEMENT ANALYSIS

o A 2D finite element model of a pavement cross-section was created in ABAQUS. The main purpose of this study is to investigate the effect of drainage layer on the saturation of the different layers of the pavement, specially subgrade. Two different cases were studied: Case I, the pavement section includes drainage and filter layers; Case II, drainage and filter layers were removed from the model. For the purpose of validation, Case I was created similar to the Hassan et., al. model and finite element results were compared (all the material properties and dimensions were adopted from Hassan et., al.). Therefore, this study has two main goals:

1) Validate the finite element model for the Case I

2) Compare the two cases

o a) Case I, Pavement Layers (Include Drainage Layer):
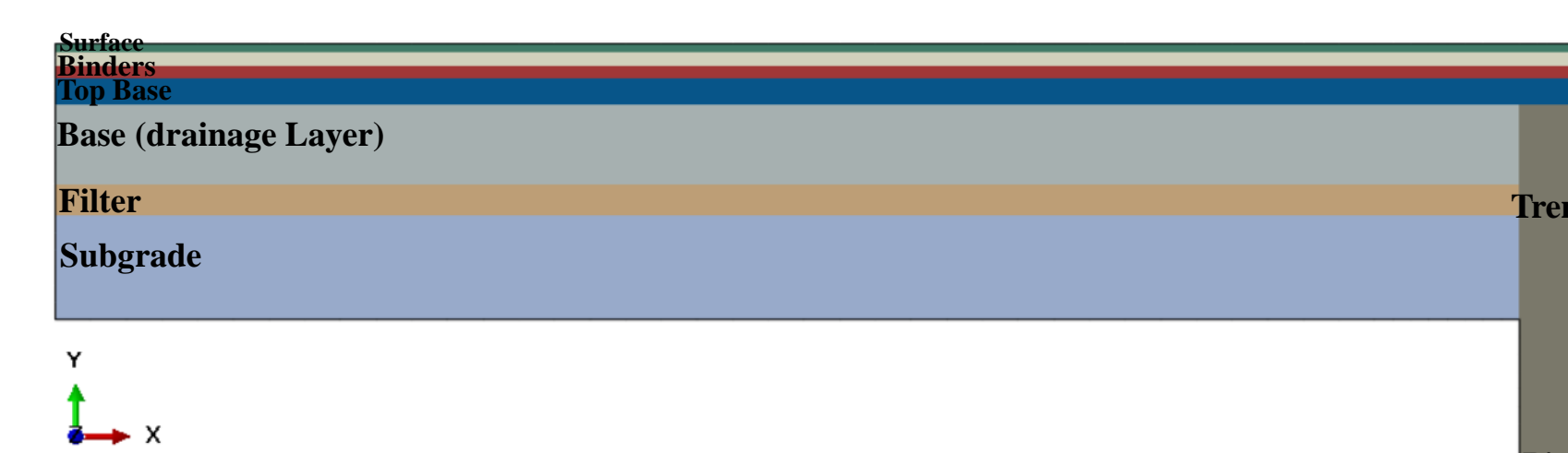
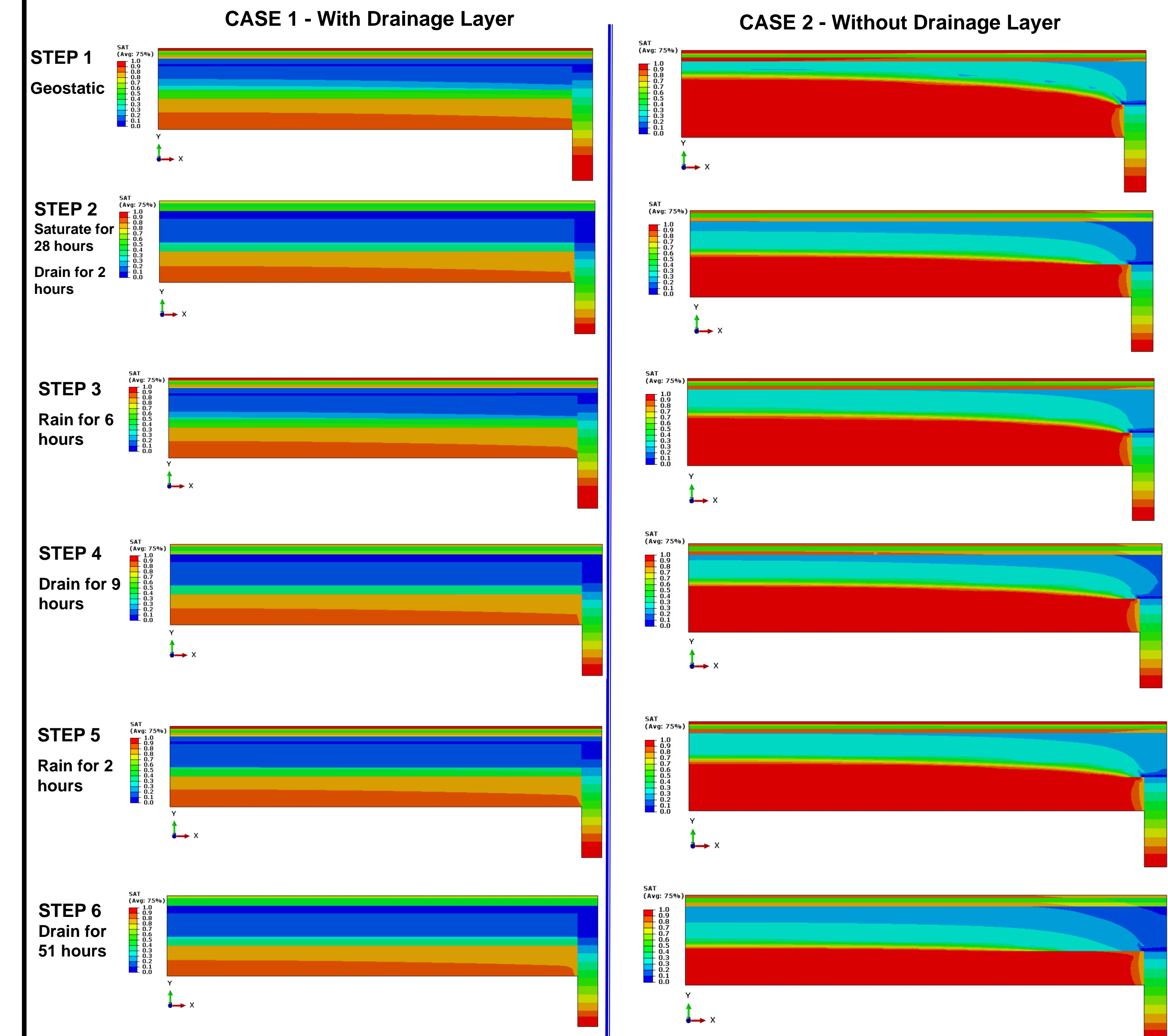o b) Case II, Pavement Layers (Without Drainage Layer):
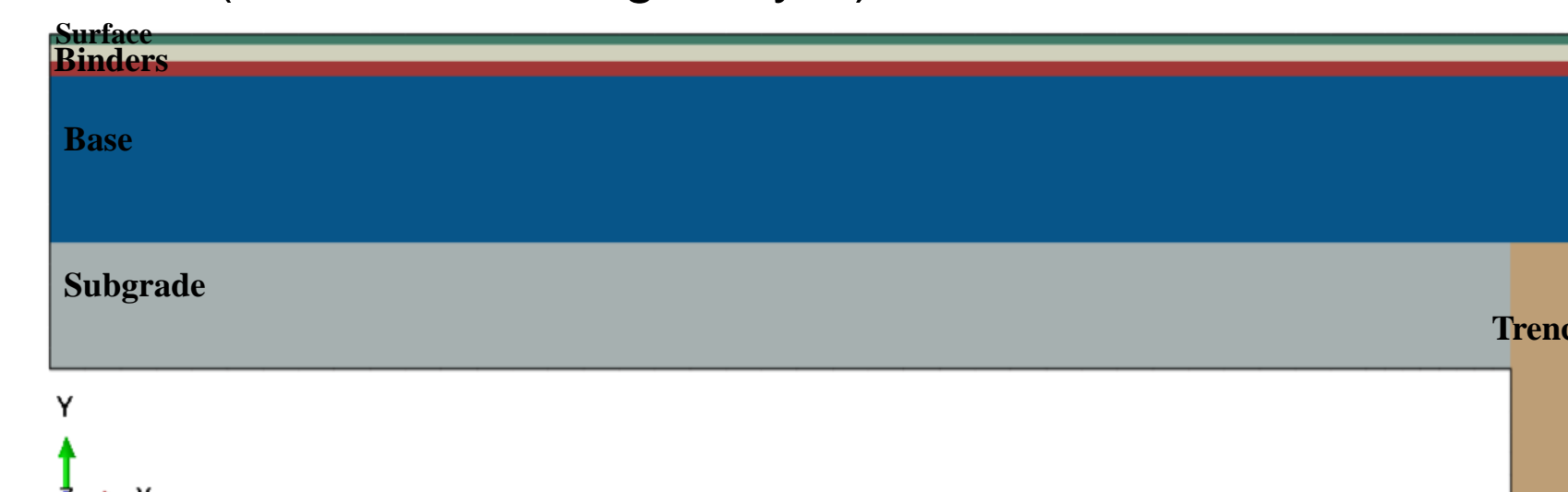
o MATERIAL PROPERTIES:

Layers	Ksat (m/s)	Porosity
#11 Surface (layer1)	1.01e-6	0.0165
#9 Surface (Layer 2)	9.5e-7	0.055
#8 Binder (Layer 3)	9.7e-7	0.0315
Base #5C (Layer4)	2.73e-4	0.164
Base #2 (Layer 5)	1.28e-4	0.05
Base #53 (Layer6)	3.64e-4	0.28
Subgrade (Layer 7)	7.7e-10	0.43
Trench	1.18e-2	0.5

o RAINFALL EVENT:

| Time (hr)	Rainfall (cm/hr)	Modeled pavement surface condition	Step number in ABAQUS
1	0.2	I	Step 2
2	0.48	I	
3	0.37	0	
4	0.19	0	
5	0.15	0	Step 3
6	0.37	0	
7	0.95	0	
8	0.87	0	
9-18	0.2	I	Step 4
19	0.9	0	Step 5
20	2.47	0	
21	1.23	I	Step 6
22-72	0.2	I	

RAINFALL EVENT IN ABAQUS

The same rainfall event was developed for both cases. The degree of saturation for the pavement section at different steps of the rainfall event is shown in the following figures.

CASE 1 - With Drainage Layer   **CASE 2 - Without Drainage Layer**

STEP 1 Geostatic

STEP 2 Saturate for 28 hours Drain for 2 hours

STEP 3 Rain for 6 hours

STEP 4 Drain for 9 hours

STEP 5 Rain for 2 hours

STEP 6 Drain for 51 hours

Pore Water Pressure variation at the bottom of the Trench during rainfall event:
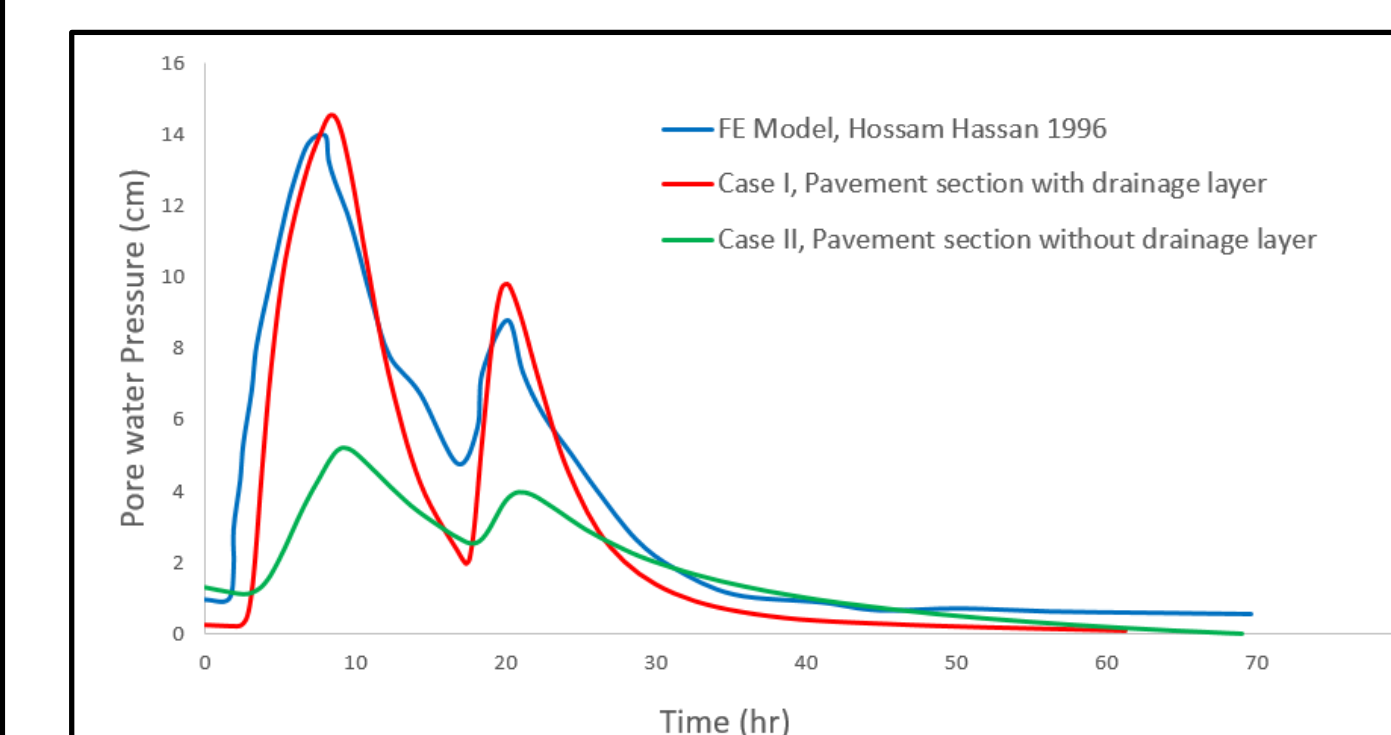
Pore Water Pressure at the end of the rainfall event:

Case I

Case II
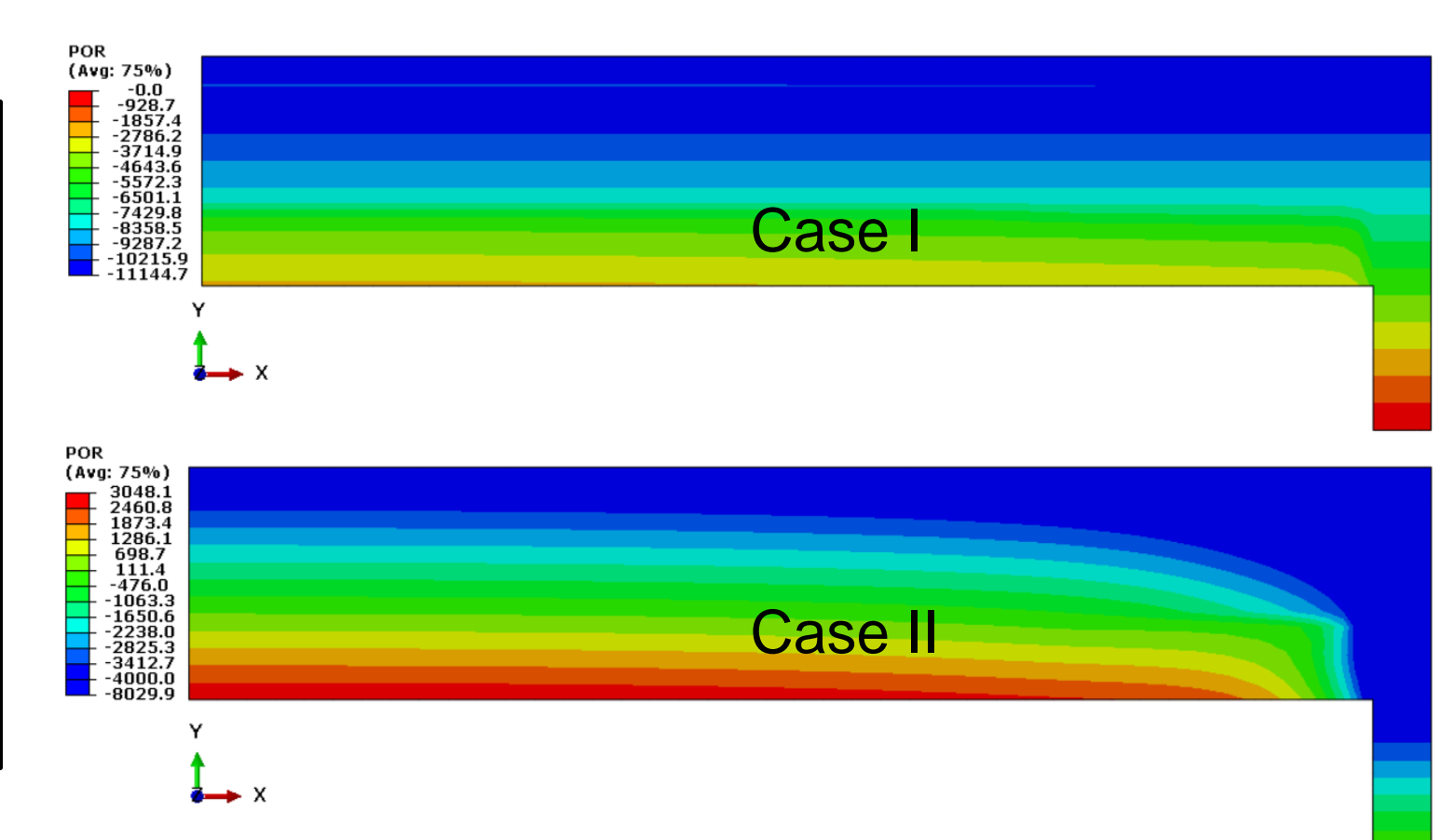
CONCLUSIONS

o Results from DRIP show excellent qualitative performance (Good, Excellent) of the pavement drainage layer for most of the base materials, except dense-graded asphalt 25 mm base.

o The current model was able to predict the behavior of pavement under rainfall events.

o The degree of the saturation in the subgrade has a maximum value of 87% when using a drainage layer, while the subgrade is always saturated (100%) for the Case II (no drainage layer). Therefore, presence of a drainage layer in the asphalt pavement section will help reduce the subgrade moisture content.

o The results indicate that the pore pressure at the bottom of the trench for the Case II is smaller than for Case I due to the fact that pavement sections without drainage layers hold more water.

REFERENCES

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