Water in the pavement system can lead to moisture damage, modulus reduction, and loss of strength. In the past, the approach taken by state agencies has focused on preventing water from entering the pavement, providing adequate drainage to remove it quickly, or building the pavement strong enough to resist the combined effect of vehicle loads and water, thus presumably reducing the detrimental effects of water on pavements. The drainage design criteria used in the past have been based on the assumption that both the flow of water through pavements and the drainage of pavement layers can be represented with saturated flow assumptions. However, full saturation of pavement systems can occur only under very specific circumstances, when positive total heads are present (e.g., surface ponding, etc.) and distributed in such a manner that saturation of the pavement system is reached. These detrimental effects can be reduced by preventing water from entering the pavement, providing adequate drainage to remove infiltration, or building the pavement strong enough to resist the combined effect of load and water. Pavement service life can be increased by 50% if infiltrated water can be drained without delay. Similarly, pavement systems incorporating good drainage can be expected to have a design life of two to three times that of undrained pavement sections. This paper gives an analysis of drainage related performance of flexible pavements.

**KEYWORDS** Drainage, Pavement Performance, Flexible Pavement

1. **INTRODUCTION**

It is a well-known fact that water in pavement systems is one of the principal causes of premature pavement failure. Indian road network at over 3.3 million km falls under one of the world's longest road networks. Most of the highways built in our country have very slow draining systems, largely because standard design practices emphasize on density and stability but place little importance on subsurface drainage. The poor sub-surface drainage on these roads leads to large amount of costly repairs or replacements long before reaching their design life. Subsurface drainage is a key element in the design of pavement systems. Indiscriminate exclusion of this element will assuredly lead to the premature failure of pavement systems, thereby resulting in high life-cycle costs. Excessive water content in the pavement base, sub-base, and sub-grade soils can cause early distress and lead to a structural or functional failure of pavement, if counter measures are not undertaken. Water-related damage can cause one or more of the following forms of deteriorations: a) Reduction of sub-grade and base/sub-base strength, b) Differential swelling in expansive sub-grade soils, c) Stripping of asphalt in flexible pavements, d) Frost heave and reduction of strength during frost melt, and e) Movement of fine particles into base or sub-base course materials resulting in a reduction of the hydraulic conductivity considerably.

Proper surface drainage can reduce the amount of water infiltrating through the pavement and is a strategy that goes hand in hand with proper subsurface drainage. Most free water will enter the pavement through joints, cracks, and pores in the surface of the pavement. Water also will enter from backup in ditches and groundwater sources. Drainage prevents the buildup of free water in the pavement section, thereby reducing the damaging effects of load and environment. Based on documented case histories, studies have shown that pavement life can be extended up to three times if adequate subsurface drainage systems are installed and maintained.

2. **NEED FOR SUBSURFACE DRAINAGE**

The damaging effects of excess moisture on pavement have long been recognized. Moisture from a variety of sources can enter a pavement structure. Figure 1 shows that moisture in the sub-grade and pavement structure can come from many different sources. Water may seep upward from a high ground water table, or it may flow laterally from the pavement edges. Knowledge of ground water and its movement are critical to the performance of pavement as well as the stability of adjacent side-slopes. Ground water can be particularly troublesome for pavements in low-lying areas. When pavements are constructed below the permanent or a seasonally high water table, drainage systems must perform or rapid pavement failure will occur. This moisture, when combined with traffic loads, voids in pavement sections, and freezing temperatures, can have a negative effect on both material properties and overall performance of a pavement system.

The most significant source of excess water in pavements is typically infiltration through the surface through joints, cracks, and other defects in the surface that provide an easy path for water. The problem only worsens with time. As pavements age and deteriorate, cracks become wider and more abundant and joints and edges deteriorate into channels through which water is free to flow. The result is more water being allowed into the pavement structure with increasing age, which leads to accelerated development of moisture-related distresses and pavement deterioration. Excess moisture in a pavement structure can adversely affect performance. While a pavement structure can be stable at given moisture contents, the pavement structure may become unstable if the materials become saturated. High water pressures can develop under traffic loads. Water in the pavement structure can freeze and expand, developing high internal pressures on the pavement structure. Flowing water can carry soil particles and lead to clogging of drains and, in combination with traffic.
Fig. 1 Sources of moisture in pavement systems

3. SUBSURFACE DRAINAGE

TERMINOLOGY

Sub-drainage alternatives vary in complexity and cost, ranging from the provision of open-graded drainage layers tied into longitudinal edge drains and outlet pipes to simply daylighting dense-graded bases. A permeable base system is the most complete subsurface drainage alternative, as it incorporates most of the drainage related components. Since it is often infeasible to design a drainage layer that will never become saturated; therefore, the design of the drainage layer is typically to satisfy three conditions: (a) to provide adequate permeability to transmit all infiltrated water during rain under partially or fully saturated flow conditions, (b) to limit the time that the drainage layer is fully saturated to a relatively short duration of a few hours or less after the rain stops, (c) and to provide enough structural stability to support pavement construction and traffic load.

3.1. The decision to include sub-surface drainage

There is little doubt about the detrimental impact of water on pavement systems in a general sense. There is considerable anecdotal and experimental evidence that adequate sub-surface drainage will increase the life expectancy of pavements. On the other hand, some experimental results have been uncertain regarding the benefit of sub-surface drainage. Sub-surface drainage adds to the complexity and cost of pavement construction. The decision-making methodology or criteria regarding sub-surface drainage varies with the agency. Christopher and McGuffey present results from a survey of agencies throughout the United States regarding the inclusion of sub-surface drainage elements. These results indicate that sub-surface drainage is employed by many agencies throughout the US, although the criteria for the drainage decision are apparently not consistent between agencies. For example, some agencies such as California always include drainage beneath concrete pavements. Other agencies focus on the anticipated traffic load: the heavier the traffic load, the greater the perceived need for sub-surface drainage.

4. HIGHWAY DRAINAGE SYSTEM

Highway drainage may be classified into the following categories:

1. Surface drainage
2. Sub-surface drainage
3. Cross Drainage Works

4.1. Surface drainage

Removal and diversion of surface water from the roadway and adjoining land is termed as surface drainage. The surface water is to be collected and the disposed of. The water is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course. Cross drainage structures like culverts and small bridges may be necessary for the disposal of surface water from the road side drains.

4.1.1. Need of surface drainage

Surface drainage deals with arrangements quickly and effectively leading away the water that collects on the surface of pavements, shoulders, slopes of embankments and cuts and the land joining the highway. The water so collected is led to natural water-channels or artificial channel, such that they do not interfere with the proper functioning of any part of the highway, including the embankment, pavement shoulders, medians, slopes, and structures.

4.2. Sub-surface drainage

Diversion or removal of excess soil-water from the sub-grade is termed as sub-surface drainage. Changes in moisture content of sub-grade are caused by fluctuations in ground water table seepage flow, percolation of rain water and the movement of capillary water and even water vapor. In sub-surface drainage of highway, it is attempted to keep the variation of moisture in sub-grade soil to minimum.

Veeraragavan A. Et al carried out “sub surface drainage is a key element in the design of pavement system. An optimum performance of a pavement system can be achieved by preventing water entering by means of a well designed subsurface drainage system. Most of the highway and airfield pavements built in our country in the past 30 years or so have very slow drainage system, largely because standard design practices emphasizes on density and stability but place little important on sub surface drainage.

4.3. Cross drainage

Whenever highway crosses a river or stream, cross drainage works have to be provided. Sometimes water from side drains also is diverted away from the road through cross drains. On highways generally, usually culverts and bridges are used as cross water way of about 6 meters, then the cross drainage structure is known as a culverts. For higher discharge and greater linear way the structure is known as a bridge.

5. EFFECTS OF DRAINAGE ON PAVEMENT DESIGN LIFE

A good understanding of the flow of water in the subsurface of the pavement may enable the design of pavement drainage systems. Following an assessment of excess moisture in the pavement system, the pavement sub-drainage system should be designed using materials that have enough permeability. Cedergren performed a study that shows that 15 billion dollars a year can be saved by designing and building pavements with good pavement drainage and sub drainage characteristics. However, proper understanding of the factors that most influence the flow of water through pavements is required to fully realize these savings.

Currently, the FHWA promotes the use of free draining materials in base and sub-base construction. The AASHTO pavement design equations show that pavement performance can be greatly improved if free draining materials are used for base and sub-base construction. The effects of excess moisture and the length of time it is retained within the pavement system are shown in the AASHTO Guide for
pavement design. This guide also contains specific structural requirements for pavements, which are weakened due to effects of moisture. The magnitude of these structural factors is directly related to the length of time that the moisture is retained in the structure. They apply not only to the design of new pavements but also to the evaluation of existing pavements. As discussed previously, for a pavement to have good drainability characteristics according to AASHTO, the structural section of the pavement should not be filled with excess water and it should not carry heavy wheel loads during periods when there is excess moisture under the pavement. For this, the water should be able to flow out of the pavement faster than it enters. The time required to drain at the end of the inflow period 8 must be short for the excess water not to remain in the structure long enough to freeze (in cold places).

6. PAVEMENT DRAINAGE CRITERIA
Based on saturated flow conditions, there are two different approaches that are typically considered for the hydraulic design of pavement systems: the steady-state flow conditions and the time-to-drain conditions. However, difficulties in estimating the design rainfall rate and the portion of rainfall that enters the pavements make the application of steady-state analyses tedious under most circumstances. Therefore, many engineers nowadays prefer the time-to-drain approach. This approach is based on flow entering the pavement until the aggregate base course is saturated. Excess runoff will not enter the pavement after it is saturated; this flow will simply run off on the pavement surface. After the precipitation event, the base will drain to a drainage system. Table 1 presents the different drainage levels for a pavement structure, according to AASHTO, for 50% of drainage. This approach drains 50 percent of the water that can be drained. It does not consider the water retained by the effective porosity quality of the material.

Table 1 presents the different drainage levels for a pavement structure, according to AASHTO, for 50 percent of drainage.

<table>
<thead>
<tr>
<th>Quality of Drainage</th>
<th>Time to Drain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>2 Hours</td>
</tr>
<tr>
<td>Good</td>
<td>1 Day</td>
</tr>
<tr>
<td>Fair</td>
<td>7 Days</td>
</tr>
<tr>
<td>Poor</td>
<td>1 Month</td>
</tr>
<tr>
<td>Very Poor</td>
<td>Does Not Drain</td>
</tr>
</tbody>
</table>

7. DESIGN CONSIDERATIONS FOR COMBATING MOISTURE
The following are the design considerations for combating moisture in flexible pavements:

7.1. Prevent moisture from entering the pavement system
Conceptually, the best approach for reducing the detrimental effects of moisture is to prevent moisture from entering the pavement system. An effective means for minimizing surface infiltration is to provide adequate cross-slopes and longitudinal slopes to drain water from the pavement surface quickly. In general, the less time the water is allowed to stay on the pavement surface, the less moisture can infiltrate through joints and cracks. However, moisture enters the pavement system from a variety of sources, and nothing can prevent it completely. Nevertheless, a proper design can minimize the amount of moisture entering the pavement system.

7.2. Provide moisture-insensitive materials
Another means of preventing moisture-accelerated damage is to use moisture insensitive or non erodible base materials that are less affected by the detrimental effects of moisture. However, although some materials can reduce or delay the detrimental effects of moisture, moisture-insensitive materials by themselves may not fully address moisture-related problems in pavements that are heavily loaded. Materials that are used often to reduce moisture-related damage are as follow.

7.3. Cement-treated base
In addition to the conventional strength testing for durability, such materials should also be checked for resistance to moisture erosion. In addition, an aggregate sub-base is recommended to prevent pumping and loss of fines from beneath the treated base in areas with adverse site conditions (e.g., high design traffic, wet climates, and high amounts of pumpable fines in the sub-grade).

7.4. Asphalt-treated base
Hot-mix asphalt base materials can also be effective in minimizing moisture problems in hot mix asphalt (HMA) pavements. The stripping of asphalt binder, caused by many factors but particularly aggregate characteristics and inadequate film thicknesses, has been the major problem with asphalt-treated base (ATB). Therefore, just as with CTB, adequate film thickness of asphalt cement around the aggregates and quality aggregates are required in ATBs to ensure long-term durability. The treated asphalt layers should be constructed using high quality aggregates, and the design should be consistent with that of a dense graded HMA base course layers defined in Mechanistic Empirical Pavement Design Guide. In general, high asphalt content ensures adequate film thicknesses around the aggregates, thereby increasing resistance to moisture.

7.5. Open graded base materials
Granular materials with a high amount of crushed materials, low fines contents, and low plasticity may also be used to resist the effects of moisture. These open-graded materials provide better resistance to the effects of moisture than dense-graded materials with high fines contents. First, open-graded materials allow easier movement of moisture through the material, so the layer remains saturated for less time. Second, the reduction of fines means there is less material that can be ejected through joints and cracks. However, stability of these untreated permeable base layers is a major concern because settlement can lead to serious problems and needs to be addressed adequately.

8. INCORPORATE DESIGN FEATURES TO MINIMIZE MOISTURE DAMAGE
Apart from using moisture-insensitive materials, several other design features can be used to minimize moisture damage. For conventional and deep-strength HMA pavements, the following design options can be used:

- Full-width paving to eliminate the lane/shoulder cold joint, which is a major
source of water infiltration in the pavement structure.

- Provision of a granular layer between the sub-grade and base course to reduce erosion and to allow bottom seepage and minimize frost susceptibility that could increase pavement roughness.
- Provision of adequate side ditches with flow lines beneath the pavement structure.

9. REMOVAL OF FREE MOISTURE THROUGH SUBSURFACE DRAINAGE

To obtain adequate pavement drainage, the designer should consider providing three types of drainage systems: surface drainage, groundwater drainage, and subsurface drainage (also called sub-drainage). Such systems, however, are only effective for “free water.” Water held by capillary forces in soils and in fine aggregates cannot be drained. All three forms of drainage share a symbiotic relationship and should be considered together in the overall drainage design for a project. The use of subsurface drainage has gained popularity over the past two decades, and many agencies now routinely specify permeable pavement structures to reduce moisture-related problems in pavements.

10. CONCLUSIONS

Drainage is a key element in the design of pavement system. However inadequate drainage leads to major cause of pavement distress due to large amount of costly repairs or replacements long before reaching their design life. Prevent moisture from entering the pavement system. A major objective in pavement design should be to keep the base, sub-base, sub-grade, and other susceptible paving materials from becoming saturated or even being exposed to constant high moisture levels over time. Four approaches commonly employed to control or reduce moisture problems are listed below:

- Prevent moisture from entering the pavement system.
- Use materials that are insensitive to the effects of moisture.
- Incorporate design features to minimize moisture damage.
- Quickly remove moisture that enters the pavement system.

It is important to recognize that no approach can completely negate the effects of moisture on the pavement system under heavy traffic loads over many years. Thus, it is often necessary to employ a combination of approaches, particularly for heavy traffic loading conditions.

There is an urgent need to study the effect of drainage quality on pavement performance in India and quantify the benefit of the good drained system with respect to undrained or poor drainage system.

REFERENCES