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HYDRAULIC DESIGN FOR PERMEABLE PAVEMENT WORKSHEET

July 14, 2000 – New Bern, NC

Why Hydraulic Design:

It is very important for permeable pavements to do two things:

1. Allow water to easily pass through top layers of the pavement (concrete or plastic blocks, sand and permeable blanket) and
2. Be able to temporarily store water in the bottom (gravel) layer, allowing it to enter shallow groundwater.

These two functions will be examined from "the ground up."

Water Storage in & Infiltration from the Gravel Layer

This gravel layer will store the rainfall as it slowly infiltrates into the existing soil. At a minimum, this storage area must be able to hold the **first inch of rainfall**, but soils in eastern North Carolina allow much higher rain levels to be stored. A permeable parking pad in Havelock was able to store all the rainfall from Hurricane Bonnie (approximately five inches) without having any runoff.

Water needs to have departed the gravel layer within 48 hours after the rainfall, but it is best when water storage is less than one day. For design purposes maximum water retention time will be set at **20 hours**. The ability to infiltrate water into existing soil depends on the permeability of the soil. Table 1 shows sample infiltration rates for suitable soils.

Table 1 – Infiltration Rates for Sandy, Loamy Sand, and Sandy Loam Soils

Soil	Typical Infiltration Rate *(in/hour)*
Sand	8
Loamy Sand	2.5
Sandy Loam	1

Designing Water Storage in Permeable Pavements:

This is a 5 part process:

1. Select Design Storm

As mentioned before this should at least be one inch, but soils in eastern NC can support higher water detention amounts. The amount of water to be stored can usually be at least 2 inches.

2. Determine Water Storage Capacity of Pavement

This is the amount of water that can be held in the pavement and is determined by the depth of the storage layer (gravel layer) and its porosity – the amount of void space between stones (n). A typical void space for the gravel layer should range between 30 and 40%. This number can be obtained from the quarry or source of the gravel. The gravel

layer thickness is determined from the structural design. In this example, eight inches of gravel is needed for structural purposes.
The storage capacity of the gravel layer is shown by the following equation:

Storage = t_{gravel} (Gravel Layer Thickness) × **n** (Void Space) =

In the given example **Storage = 8" × 0.30 = 2.4"**.

2a. Comparing Storage Amount with Design Storm

Does the gravel layer store at least as much as the design storm? If so the pavement design is so far adequate. In the design example the gravel layer can actually store 2.4" of water which is higher than both the minimum design storm (1") and the desired design storm of 2". Therefore the water storage design is sufficient.

3. Select Exfiltration Time

As previously discussed water must leave the gravel layer within at least 48 hours. Any in-situ soil that retains water for a longer period is NOT a candidate for using permeable pavements. It is best, in fact to retain water no longer than 20 hours. 20 hours is the suggested Design Exfiltration Time.

4. Calculate Drawdown (Exfiltration) Time

The amount of time that is actually needed to have the water evacuate the gravel layer is the most important part of the design. It is a function of the storage volume (determined in part 2 of this design) and the in-situ soil's infiltration rate. This rate is given in Table 1 of this handout.

To calculate the time needed to "empty" the gravel layer of its water, the following equation can be used:

Time of Drawdown = Storage ÷ Infiltration Rate

In the example being reviewed **Time of Drawdown** = **2.4" ÷ 2.5 in/hr** (assuming loamy sand in-situ soil) ≈ 1 hour.

The number is greatly dependent upon the in-situ soil's infiltration rate. If the soil gets much less permeable then the time of drawdown will balloon.

5. Compare Actual Drawdown with Design Exfiltration

The actual drawdown should occur within the amount of time allotted for drawdown by the designer. If actual drawdown time is longer than the design time, then the site is probably not a candidate for using permeable pavements.
In the example given the actual **drawdown time** (1 hour) is much less then the allowable **design time** (20 hours). Therefore the in-situ soil combined with the gravel storage layer provide an acceptable condition in which to construct permeable pavers.

Infiltration "from the Top"
Many people believe that runoff from permeable parking lots occurs when the pavement becomes saturated with water and can no longer store any more water. However, this is typically NOT the case. Most runoff from permeable lots is generated by water not being able to infiltrate the surface layer (concrete block or plastic grid filled with sand or topsoil) of the pavement quickly enough.
An intense rainfall can overwhelm the infiltrative capacity of the surface layer. Exactly what degree of storm is calculated below.

Calculating Storm Intensity to Produce Runoff
This is a two part process:
1. Find Surface Layer Infiltration Rate, and
2. Calculate Effective Rainfall to Match Infiltration Rate

1. Surface Layer Infiltration Rate

The soil used to fill the open spaces in the plastic or concrete pavers significantly alters the surface layer infiltration rate. Again using Table 1, some basic infiltration rates can be found. A masonry sand has a very high infiltration rate (8-10 in/hour), but limits grass growth. Using an existing topsoil (such as a sandy loam – infiltration rate of 1 in/hr) makes for a substantially lower infiltration rate, but does allow for better growth of ground cover.

For a design example assume voids in the top layer are filled with a very sandy soil (infiltration rate of 8 in/hr).

2. Matching Effective Precipitation Rate with Surface Layer Infiltration Rate

The top layer is a mix of impermeable areas (such as the concrete blocks) and very permeable areas. The soil in these spaces must be permeable enough to allow infiltration of both rainfall that falls directly on top of it and runoff from immediately adjacent impermeable areas. In effect the "precipitation" rate relative to the open spaces is inversely proportional.
An example calculation of effective precipitation follows: assuming a concrete block that is 60% impermeable and 40% open space filled with sand, the effective precipitation rate on the open areas of the pavement would be:

Effective Precipitation Rate (P_{eff}) = Precipitation Rate (P) ÷ Percent of Permeable area = **P** ÷ 0.4 = 2.5 **P**.

By setting effective precipitation to infiltration, the actual precipitation rate at which runoff would occur can be calculated. Using the above information and an infiltration rate of 8 in/hr of sand, the runoff producing rainfall rate is found as follows:

$\mathbf{P_{eff}}$ = Infiltration Rate = 8 in/hr = **P** ÷ 0.4

P = 3.2 in/hr

So, a Rainfall rate of 3.2 inches/hour on a pavement with 40% open space would produce the same need for drainage as a rainfall rate of 8 inches/hour. This is the approximate permeability of sand used to fill concrete pavers. To induce runoff from this site, rainfall intensity must exceed 3.2 inches/hour.

If a plastic paver had been used (with approximately 10% impermeable area and 90% void space) the rainfall intensity needed to produce runoff will increase to roughly 7 in/hr. However, a plastic paver filled with loamy sand topsoil would produce runoff when storm intensities were between 2 and 2.5 in/hr.

Runoff Coefficients:
Research in Kinston, NC, and other states indicate substantial runoff reduction at properly sited, designed, constructed, and maintained permeable pavement applications. For storms, which tend to induce flooding (such as those with a 2 year return period) a permeable pavement *runoff coefficient* for *the Rational Method varies from 0.25 to 0.40.* This number is still "young" and additional research is needed to verify or suggest a new coefficient and does not include the effect of time. See attached handouts for more detail on the Kinston, NC, site.