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Using a Novel Permeable Pavement on the Urban Flood Water Management

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Abstract: Urbanization effects will add the impervious area and reduce the infiltration ratio of groundwater, so as to increase the chance of flooding. Traditionally, the discharge of surface water is to build the great drainage system, which needs considerable cost and land. The concept of sponge city is to improve the land absorption capacity, such as the increase of ground permeability, so as to reduce the chance of flooding. This study adopted a novel permeable pavement named JW pavement to add the permeable rate of land, so as to reduce the flood of the urban area. The detention equation of the permeable pavement was established by the hydrologic continuous equation. The parameters in the detention equation, including the void ratio of graded layer under the pavement and the discharge coefficient of the water pipe were measured to obtain the detention volume of unit permeable pavement (1m×1m). The equation of detention volume can be used to estimate the detention effect of JW pavement.

Keywords: *Sponge City, JW Ecological Engineering, Hydrological Continuous Equation, Urbanization Effects, Permeable Pavement.*

Introduction:

Generally speaking, the global warning induces the extreme climate, where the annual precipitation changed little, but the number of rain days is reduced and rainfall depth increases. Therefore, the threat of water shortages and floods increases. In the city, the main influences of the extreme climate are (1) The occurrence of flood exceeding the capacity of drainage system will increase; and (2) The effect of heat island will increase the temperature in summer.

The definition of sponge city is that some regional centres 'soak up' population and business from a 'pool' of surrounding areas, thereby appearing as 'oases' of growth in areas of population decline (Argent et. al. 2012). However, Liu et. al. (2012) defined the sponge city is that the precipitation can be stored under the ground during the flood period, and evaporated into the air during the sunny day. The JW pavement (according to its inventor's name), which is a high infiltration rate pavement, can achieve the ideals of sponge city. This study calculated the detention volume of JW pavement to be the application basis of sponge city. The governing equation of detention volume was established by the hydrological continuous equation. A laboratory experiment is executed to obtain the discharge coefficient of water pipe.

Materials and Control Equation:

(1) JW pavement

Figure 1 displays the 1 meter unit of JW pavement. The top-down configuration is : (1) the 15 cm thick concrete pavement, with water pipe spacing of 10cm, inlet pipe diameter of 1cm, two kinds of outlet pipe diameter 1.2cm and 1.5cm, respectively; (2) the permeable gravel layer, thick of H_g; (3) the permeable base soil layer, thick of H_b; and (4) the impermeable rock layer. When flood occurs, the precipitation can drain into the gravel layer through the water pipe, and infiltrate into the base soil layer before the time of soil saturation reach. Figure 2 displays the construction process.

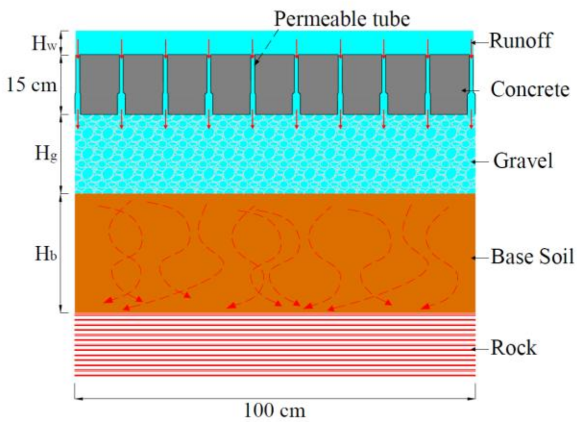


Figure 1: The schematic diagram of JW pavement

(a) The layout of gravel layer

(b) The breathable water guide frame

(c) The concrete pouring

(d) The JW pavement

Figure 2: The construction process of JW pavement

Firstly, the gravel layer was laid on the base soil (Figure 2(a)). Secondly, the breathable water guide frame was placed on the gravel layer (Figure 2(b). Thirdly, the concrete was pouring to fill the void of the breathable water guide frame (Figure 2(c)). Figure 2(d) is the completed picture.

(2) Detention volume calculation

Assuming the permeable layer including the gravel layer and the base soil layer, are the detention pond, where the storage volume (s) is the pore volume of permeable layer. The inflow (i) is the drainage rate of flood. The outflow (o) rate can flow into the downstream based on the gravity effect.

The hydrological continuous equation (Chow et al., 1988) was shown as follows:

$$\frac{ds}{dt} = i - o \qquad (1)$$

Chen & Hong (1999) adopted above equation to calculate the detention volume. Equation (1) can be resolved by the perturbation method (Chen & Hong 2002), the simplified method (Hong et. al. 2006), numerical method(Hong 2008a) and graphic method(Hong 2008b). The laboratory experiment can alos used to verify the numerical method (Hong 2010). This study adopted Equation (1) to calculate the detention volume of permeable layer.

The storage volume s depends on the pore ratio of permeable layer. Assuming the volume of permeable layer v_t, the solid volume v_s, the maximum storage volume s_m, the pore volume v_v, the following relationship exists

$$s_m=v_v=v_t-v_s \qquad (2)$$

The maximum storage ratio S_m is

$$S_m=v_v/v_t=(v_t-v_s)/v_t \qquad (3)$$

where Vr (=v_v/v_t) is the void ratio. If the V_r is known, the maximum storage volume can be obtained.

The water pipe of JW pavement is similar to the morning glory spillway(U.S. Bureau Of Reclamation, 1965), and the discharge equation Q is

$$Q = C_d L H^{1.5} \qquad (4a)$$

where C_d is the discharge coefficient; $L = 2\pi R_s$ is the perimeter of water pipe; H is the water depth; R_s is the radius of water pipe. Based on the number of water pipe=81 within the unit area (1m×1m), the radius of water pipe is 0.5cm, and L=0.0628318m, the inflow discharge of unit area is

$$i = 81Q = 2.54 C_d H^{1.5} \quad (m^3/sec) \qquad (4b)$$

If Cd and H are known, I can be calculated by Equation (4b) .

The parameters of Detention Volume:

(1) The Void ratio of gravel layer

The gravel with the average grain size 1cm was adopted. The measurement of void ratio was depicted below:

A. Select a container to fill of water to calculate the volume v_t, and pouring out the water.
B. Put some gravels into the container, and shock the container to reduce the void.
C. Repeat procedure (2) until the container with the full gravel.
D. Pour water v_v into the container to fill the void.

In this study, the container volume v_t =1.4m^3, v_v=0.44m^3, the void ratio v_v = 31.4%, which represent that the storage volume is 31.4% of total volume. The corresponding storage volume is 0.314Hg.

(2) The discharge coefficient of water pipe

The acrylic model of JW pavement is shown in Figure 3, where the length and the width is 58cm, and the height is 80cm. Above the JW pavement (= 10.5cm) is the overland flow depth.

The number of the water pipes is 16, and the control area is 1936cm^2.

(a) Top view

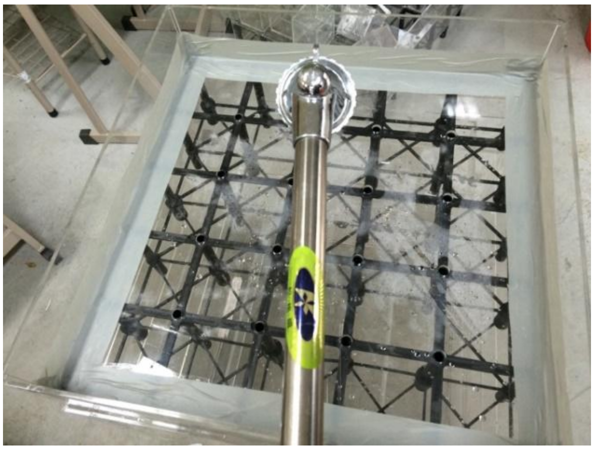
(b) Side view

Figure 3 Model of JW pavement

The procedure of the laboratory experiment was illustrated as following:

A. Install the drain system above the JW pavement (figure 4(a)).
B. Pour a steady flow into the JW pavement (Figure 4(b)). When the steady water depth above the JW pavement reaches, the water depth of storage area was recorded as h_1, and the timer was started.
C. When the water depth of storage area was reached the maximum water depth h_2, the timer was stop to calculate the storage time t, and the rising water height $h=h_2-h_1$.

The storage volume V=58×58×h=3364h (cm^3), and the total discharge Q_t=V/t (cm^3/sec). The discharge of single water pipe is $Q_s=Q_t/16$. Four kinds of discharge were adopted to measure the discharge coefficient. Table 1 is the outcome of laboratory experiment, where the average C_d = 2.69. According the discharge coefficient obtained by the laboratory experiment, the drainage discharge of unit area (1m^2) for various water depth can be calculated by Equation (4b) shown in Table 2.



(a) The drain system installation

(b)The adding water test

Figure 3 The laboratory experiment of discharge coefficient

Table 1 The discharge coefficient calculation

H (cm)	h(cm)	V (cm^3)	t (sec)	Qt(cm^3/sec)	Q_s (cm^3/sec)	C_d	Average C_d
5	44.5	149698	110.12	1359.41	84.96	2.42	2.42
5	43.5	146334	102.25	1431.14	89.45	2.55	
5	43.5	146334	112.32	1302.83	81.43	2.32	
5	43.5	146334	108.51	1348.58	84.29	2.40	
3.5	45	151380	190.14	796.15	49.76	2.42	2.50
3.5	45	151380	170.28	889.01	55.56	2.70	
3.5	44.5	149698	183.58	815.44	50.96	2.48	
3.5	45	151380	192.11	787.99	49.25	2.39	
1.5	46	154744	521.11	296.95	18.56	3.22	3.15
1.5	47	158108	631.4	250.41	15.65	2.71	
1.5	45	151380	476.37	317.78	19.86	3.44	
1.5	45.5	153062	512.55	298.63	18.66	3.23	

Table 2 The drainage discharge of unit area

h (m)	drainage discharge (m^3/sec)	drainage discharge (m^3/hour)
0.0025	0.00085	3.07
0.005	0.00242	8.70
0.01	0.00683	24.60
0.015	0.01255	45.19
0.02	0.01933	69.57

According the outcome of Table 2, the drainage volume per unit area is large enough to flush the flood of short duration precipitation.

Conclusion:

This study adopted a novel permeable pavement named JW pavement to achieve the sponge city. The hydrological continuous equation was used to build the estimation equation of detention volume. The gravel layer is the ground detention pond, which occupied 31.4% of total volume by laboratory experiment. The inflow rate can be estimated by the equation of the morning glory spillway, and the discharge coefficient C_d = 2.69. The inflow rate is large enough to flush the flood of short duration precipitation.

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