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A modified method for the design of pervious concrete mix

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HIGHLIGHTS

- The new mix design method for pervious concrete is based on the excess paste theory.
- The *w/c*, cement, aggregate content and the compaction energy were determined.
- The permeability of concrete is always sufficient to drainer the rainwater.

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ABSTRACT

As a new material type for pavement, pervious concrete should be designed to maintain both porosity and the structural strength. The actual mix proportions for pervious concrete depend on the application, the mechanical properties required and the materials used. Actually, the mix proportions of pervious concrete were determined for locally available materials based frequently on trial batching and experience. Another analytical method should be developed to facilitate the concrete producers. Based on the assumption that the cement paste only plays a role of coating, it does not fulfill the void among the grains of gravel; this paper focuses on one modified method for the design of the pervious concrete. The volume cement paste is divided by the surface area of the aggregates to determine the thickness of the excess paste. A scaling factor has been defined to evenly distribute the cement paste toward the size of gravel. Moreover, a binder drainage test is proposed to determine the critical *w/c* ratio towards to prevent the flow of cement paste to the lower layers of concrete under the action of vibration or compaction. The pervious concrete has been formulated according to this method to validate it. The mechanical and hydraulic tests are performed to characterize the pervious concrete. The obtained pervious concrete presents a large sufficient permeability (1 mm s^{-1}) for draining rainwater and good mechanical resistance (R_c = 28.6 MPa) with regard to typical pervious concrete applications such as parking lots, walkways and low-traffic roadways. In addition, the mechanical strength of pervious concrete in this research is found higher than that generally reported by other authors. The results indicate that the theoretical mix design method is a successful theory for an optimizing composition of pervious concrete.

1. Introduction

With the population growth and the continual urbanization, our cities are being covered with the impervious surface areas such as residential and commercial buildings. Because of the lack of water and air permeability of the common concrete pavement, the storm water is not filtered underground, the runoff is rapidly increased. Therefore, the drainage system gets overloaded and flash flooding becomes inevitably. In addition, with the impervious surface, it is difficult for soil to exchange heat and moisture with air; therefore, the temperature and humidity of the Earth's surface cannot be adjusted. This brings the phenomenon of greenhouse and hot land effects in city. At the same time, the plash on the road during a rainy day reduces the safety of traffic of vehicle and foot passenger [1].

In civil engineering, the decrease of the ground water level can cause subsidence of soil of several meters, deconstruct buildings, structures and works.

Pervious concrete (PC) is a special type of concrete with continuous porosity ranged from 15% to 35% and the presence of interconnected large pores system allows the water flow easily through the pervious concrete [2–6]. In recent decades, the use of pervious concrete for the construction of secondary roads, parking lots, driveways, walkways and sidewalks is increasing continuously because of its various environmental benefits such as [1–4]:

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Nomenclature

a (%)	percentage of aggregate larger than 80 μm in the aggregate mixture
b (%)	absorption of aggregate (sand included)
C (kg m^{-3})	Ciment content
D_i (m)	average diameter of aggregate of the class i
D_p (mm)	diameter characteristic of pores
e_i (m)	thickness of the layer of the excess paste covering grain i
m_G (kg)	weight of aggregate in on meter cubic of concrete
k (–)	a scaling factor
m_i (kg)	mass of size D_i aggregate grain
N_i (nbr)	number of size D_i aggregate grains of the class i
N (nbr)	number of particle aggregate in concrete
P_t (%)	total porosity of concrete
P_p (%)	porosity of cement paste
P_0 (%)	initial porosity of cement paste
Q (%)	void content of dry compacted aggregate
R_c (MPa)	compressive strength at 28 days
R_t (MPa)	tensile strength at 28 days
S (m^2)	total surface area of the grains aggregate in the mixture
S^* (m^2)	total surface area of the grains average of diameter $d_i + e_i/2$
S_i (m^2)	surface of grain size D_i
S_{si} (m^2 kg^{-1})	specific surface of aggregates of class i in the mixture
V_{fines} (m^3)	volume of fines in concrete
V_G (m^3)	solid volume of aggregate
$V_{G>80}$ (m^3)	volume of a greater than 80 μm aggregate
V_P (m^3)	volume of cement paste
V_{PC} (m^3)	volume of compact paste
V_{PE} (m^3)	volume of excess paste
V_i (m^3)	volume of a size D_i grain
V_v (%)	volume of void in concrete
V_{total} (m^3)	total volume of concrete
$V_{W/G}$ (m^3)	volume of the water retained by the aggregate
W (kg m^{-3})	quantity of water in concrete
u	ratio between total volume of void and total solid volume of concrete
x	ratio between aggregate volume and total solid volume of concrete
α	degree of hydration of cement
$\alpha(\infty)$	degree of hydration of cement at infinite time
β (–)	factor definite
$\rho_{dry,compacted}$ (kg m^{-3})	dry, compacted bulk density of the aggregate
$\rho_{specify}$ (kg m^{-3})	specify bulk density of the aggregate
ρ_C (kg m^{-3})	specify density of cement
ρ_W (kg m^{-3})	specify density of water
γ (–)	compactness of aggregate
w/c	ratio of the weight of water to the weight of cement

1. The storm water can rapidly filtered into soil, and the groundwater resources can recharge.
2. The surface is air and water permeable and the soil below can be kept wet. It improves the environment of road surface.
3. The pervious concrete pavement can absorb the noise of vehicles, which creates quiet and comfortable environment.
4. The pervious concrete pavement materials have holes that can cumulate heat. The pavement can adjust the temperature and humidity of the Earth's surface and eliminates the phenomenon of hot island in cities.

Since its various environmental benefits, pervious concrete is one of the most important emerging technologies for sustainable facilities and infrastructure. Therefore, pervious concrete is recognized as the best solution for storm water management and one of the key elements of sustainable development by US Environmental Protection Agency [2,3].

The mix design of pervious concrete is different from the conventional one. The materials mix design of PC is composed of Portland cement, uniform coarse aggregate (allowing relatively little particle packing), approximately 7% fine aggregate by weight of total aggregate and water. The addition of a small amount fine aggregate as sand provided additional compressive strength, better durability and high resistance to freeze/thaw cycles. Generally, pervious concrete mix consists of 270–415 kg m^{-3} of cement, 1190–1480 kg m^{-3} of aggregate and water to cement ratio ranged from 0.27 to 0.40. The typical 28-day compressive strength ranges from 3.5 to 28.0 MPa and permeability coefficient varies from 0.2 to 5.4 mm s^{-1} [2,3]. Additionally, the characteristic pore sizes range from 2 to 8 mm depending on the type of aggregates and the method of compaction [2,7].

Many previous studies have reported the proprieties of pervious concrete in varying the water-to-cement ratio, aggregate-to-cement ratio, aggregate sizes, binder material type or effects of compaction energy [1–8]. However, the number of publications on the method for the design of pervious concrete mix is very limited. There can be mentioned here the American concrete institute method [2], Zouaghi's method [8] and Zheng's method [9]. Moreover, these design methods are not complete; they present many disadvantages, as shown in Table 1. For example, they do not indicate how to determine the w/c ratio or they do not take into account the effect of compaction on the properties of concrete, etc. Therefore, there are no recognizing methods to establish the mix design of pervious concrete at the present time, the pervious concrete mixture proportions are always selected from experimental studies [3].

2. Principal of the proposed mix proportioning method

In this paper, a modified method is proposed for mix design of PC. This method is based on the quantification of the layer of cement paste coating the gravel and on the assumption that the cementious paste act only as a coating; it does not fulfill the void among the grains of gravel. This method of mixture proportioning is divided into three steps: the determination of aggregate volume, cement paste volume and water–cement ratio.

2.1. Determination of aggregate volume

Aggregate occupies most of the pervious concrete's volume and is the principal load-bearing component. In this section, four hypotheses were adopted for the determination of aggregate volume.

Hypothesis #1. To facilitate the calculation, the aggregate is assumed of spherical shape. Only a perfect sphere can be characterized by a single value of size which is the diameter. The purpose of this equivalent sphere hypothesis is to describe an object in three dimensions by a single value.

Fig. 1 shows the components of ordinary concrete in which aggregates are spaced by the cement paste. Assuming that, the aggregates are compacted at maximum to have the solid volume