MIXTURE RATIO DESIGN METHOD FOR POROUS CONCRETE PERMEABLE BASE

Mulian Zheng[1], Shuanfa Chen[2], and Binggang Wang[3]

ABSTRACT

As a new kind of material for permeable base, mixture ratio design of porous concrete should ensure both the porosity and the mechanical strength. Based on Talbol Formula and foreign experiences, four kinds of gradation of porous concrete are designed and effective particle size and uniform coefficient are taken as the effective descriptive targets of aggregate gradation. Three factors of cement dosage, water cement ratio and aggregate gradation are considered in an orthogonality test with four levels adopted in every factor. Through variance analysis of the tests results, it can be drawn that when confidence probability is 95%, the factors that evidently affect 7d compressive strength are gradation and cement aggregate ratio, and the factors evidently affect effective porosity are gradation, cement aggregate ratio and water cement ratio. While when confidence probability is 90%, gradation, cement dose and water cement ratio all have evident influence on 7d compressive strength and effective porosity. Based on the test results, a series of regression relationships of 7d compressive strength and effective porosity of porous concrete are derived. Finally, the empirical equation method of mixture ratio design for porous concrete is proposed.

INTRODUCTION

Most of the water falling on pavement flows outside of the roadside and subgrade through pavement cross slope and longitudinal slope, while there is some water penetrating into the pavement structure along pavement joints, cracks and surface void and becoming main water sources causing pavement structure damage. When the geography is flat, the earth surface is pooling and the embankment is low, water can also penetrate into pavement structure from side slope of the road. Furthermore, the capillary action and evaporating movement of ground water can also cause water enter the interior of pavement structure, which can give off gradually by seepage flow to subgrade and roadside. But if the water in pavement structure cannot give off in time, it will soak the pavement materials and subgrade, which will decrease the strength and increas the deformation. More seriously, high pressure water will be formed under the function of traffic loading, which will cause many damages. Therefore, much study has been developed to decrease or even eliminate pavement water damage through designing reasonable permeable base materials and internal drainage system.

Researches show that the permeable base must fulfill three demands [1-8)]. First,

[1]Ph.D. Associate Professor, College of Highway engineering, Chang'an University, Nan-er-huan Road, Xi'an 710064, P. R. China, Email: zhengmulian@163.com

[2]Ph.D. Professor, Vice dean, School of Materials Science and Engineering, Chang'an University, Nan-er-huan Road, Xi'an 710064, P. R. China, Email: chensf@chd.edu.cn

[3]Professor, College of Highway engineering, Chang'an University, Nan-er-huan Road, Xi'an 710064, P. R. China, Email: wangbinggang999@163.com

It must have enough permeability to give off the water entered pavement structure in schedule design time. Second, it must have certain strength to support pavement construction. Finally, it must have enough strength to fulfill the demands of pavement structure. Presently, there are three ways to solve the problem in the world. The first is removing some fine grains from close-graded aggregate to get demanded permeability and form open-graded aggregate permeable base. The second is applying cement or asphalt to stabilize open - graded aggregate to form binder stabilized permeable base. The last is increasing porosity and cement dose to get higher permeability, strength and stability so as to form porous concrete permeable base.

The mixture ratio design of porous concrete is different from common concrete, and it has some special demands in aggregate gradation, cement dose and water cement ratio in order to ensure the porosity and mechanical strength as pavement structure layer. However, the relationship between high permeability and strength restricts each other, and every aspect of factors should be taken into account when designing the mixture ratio.

RAW MATERIALS

Cement. The cement with long intial setting time should be adopted firstly and the other characters of cement should fulfill the demands of correlated technical specification. 32.5 P. O. Cement of Qinling brand is used in the test, and some technical targets are listed in **Table 1**.

Table 1. Technical targets of cement

Test items	Initial setting time /min	final setting time /h	Fineness /%	3d strength /MP_a		28d strength /MP_a	
				Bending	Compression	Bending	Compression
Standard requirements	≥45	≤10	≤10.0	≥2.5	≥11.0	≥5.5	≥32.5
Test results	218	5.72	3.8	4.5	23.4	8.6	47.7

Coarse aggregate. Coarse aggregate used in porous concrete should be clean, hard and durable crushed stone. The crushed lime stone from Xi'an is used in the test and some technical targets are listed in **Table 2**.

Table 2. Technical targets of crushed stone

Test items	Apparent relative density	Bulk density /$g\cdot cm^{-3}$	Mud content /%	Flat and elongated particle content /%	Crushed value /%
Standard requirements	——	——	≤1	≤15	≤30
Test results	2.7	1.5	0.9	8.9	6.3

Others. There should be enough water for porous concrete to fulfill the demands of cement hydration and compaction. The paper adopted drinking water to mix and cure porous concrete.

AGGREGATE GRADATIONS

Gradation design principle. Aggregate component design of porous concrete should satisfy the demands of certain porosity and forming high strength after mixed with cement paste. Desirable porous concrete is that the coarse aggregates are interlocked and not interfered after compressed, and there is large friction to form space framework structure. In accordance with Talbol Formula[1)] and foreign experience[9)], authors designed four kinds of gradation listed in **Table 3**.

$$P = 100\left(\frac{d}{D}\right)^{n} \qquad (1)$$

In the formula, P means the passing percentage of quality through every seive size, %; d means seive size, m; D means the maximum particle size, mm; n means test index.

Table 3. Aggregate gradation of porous concrete

Sieve size /mm	Passing percentage of quality /%			
	Gradation 1	Gradation 2	Gradation 3	Gradation 4
31.5	100	100		
25			100	100
20	76～87	76～87	90～100	
16				25～60
10	0～5	50～71	20～55	
5		0～5	0～10	0～10
2.5			0～5	0～5

Description of aggregate gradation. For aggregate gradation being a kind of distribution, when designing the composition of porous concrete, there should be effective parameters to describe it. Practices have shown [1)] the effective particle size and homogeneity coefficient are effective targets. Furthermore, since porosity is one of the design targets of porous concrete, the percent voids in aggregate can also be used to appraise the gradation indirectly.

1. Effective particle size

Effective particle size D_x is a particle size that the mass passing ratio for those size less than it is x% in sieve curve. When x equates 10, it is also called as Hazen effective size.

Effective size D_{10} can characterize the permeability of materials. When there are more grains with diameter exceeding effective size D_{10}, the material permeability is better.

2. Homogeneity coefficient

Homogeneity coefficient (C_u) is the ratio of particle size with percentage of passing particle 60% to 10%. That is

$$C_u = D_{60} / D_{10} \qquad (2)$$

Homogeneity coefficient characterizes the expanding degree of grain size. It shows the density of material gradation and indicates material permeability indirectly. Study shows [1)] that the combination of big effective particle size and small homogeneity coefficient can get high permeability coefficient. The effective particle size and coefficient of homogeneity of the four kinds of aggregate gradation in **Table 3** are shown in **Table 4**.

Table 4. Effective size and homogeneity coefficient of aggregate

Gradation	Gradation 1	Gradation 2	Gradation 3	Gradation 4
Effective size D_{10} /mm	10.68	5.47	5.56	5.84
Effective size D_{60} /mm	16.56	9.94	13.12	18.33
Homogeneity coefficient C_u	1.551	1.636	2.360	3.139

ORTHOGONALITY TEST OF MIXTURE RATIO DESIGN

Forming method of test piece. Porous concrete is a material between cement stabilized open-graded crushed stone and common lean concrete, and different forming method will affect its strength and porosity evidently.

Presently, cement - stabilized crushed stone permeable material is formed by static pressure method in accordance with common cement-stabilized crushed stone. However, open-graded crushed stone has little fine aggregate which makes coarse aggregates contact on points and be often crushed easily, which decreases its strength and porosity greatly. Although the static pressure method can imitate actual construction well, the compaction standard to determine the maximum dry density is difficult to control and the manipulation of the method is more complex.

Document 10) put forward an improved compaction method, with the compaction time being determined by the standards of compacting fully and the stones not being crushed. This method changes the idea of static pressure method with searching for the maximum dry density by compaction test. But it is also complex to determine the compaction time and make the mixture surface of every layer be crushed easily.

To skeleton void structure such as porous concrete, the static pressure method is not suitable. Since many characters of porous concrete are similar to common concrete, it can be looked as a special kind of common concrete. At present, vibration method is the common forming method for common concrete, and lots of previous tests show it is also fit for porous concrete.

For the above reasons, authors adopted vibration method to form porous concrete and cued the test pieces with standard curing method.

Orthogonality test design. There are many factors, such as cement dose, water cement ratio, aggregate gradation and cement strength etc to influence the mechanical behavior and permeability of porous concrete, with the cement dose being expressed with cement aggregate ratio. Since the cement used widely in actual base construction is grade 32.5, the tests mainly take account into three factorsof cement dose, water cement ratio and aggregate gradation with each factor taking four levels according to experience, which are shown in **Table 5**. According to **Table 5** and the orthogonality design table $L_{16}(4^5)$, the mixture ratios are arranged in **Table 6**, in which the aggregate content is the product of aggregate bulk density under the condition of vibrating compaction and the reduction coefficient of 0.98 [11)].

Table 5. Factors and levels table of orthogonality test design

Levels	Factors		
	A Gradation	B Cement aggregate ratio	C Water cement ratio
1	Gradation 1	1 : 8	0.33
2	Gradation 2	1 : 9	0.36
3	Gradation 3	1 : 10	0.39
4	Gradation 4	1 : 11	0.42

1-3	4.61	33.37	1908.15	3-3	4.61	33.57	1844.46
1-4	3.30	33.64	1866.65	3-4	4.67	34.06	1885.95
2-1	6.77	28.14	1970.35	4-1	7.58	24.28	1991.15
2-2	5.60	30.96	1921.50	4-2	5.92	30.31	1920.00
2-3	5.03	31.70	1911.10	4-3	4.49	32.27	1872.60
2-4	4.16	33.00	1866.65	4-4	3.35	33.12	1857.85

Table 8. Regression equations of porous concrete formed by vibrating

Dependence variable	Independence variable	Regression equations	Correlation coefficient	Sequence No.
$f_{c,7}$	D_{10}, C	$f_{c,7} = -3.133 - 0.118D_{10} + 0.050C$	0.945	(3)
	D_{10}, C, W/C	$f_{c,7} = -6.131 - 0.118D_{10} + 0.049C + 8.116W/C$	0.969	(4)
n_e	C	$n_e = 51.313 - 0.109C$	0.863	(5)
	D_{10}, C, W/C	$n_e = 60.283 + 0.316D_{10} - 0.094C - 37.181W/C$	0.936	(6)

In the equations, $f_{c,7}$ is the 7d compressive strength of porous concrete, MPa; n_e is the effective porosity of porous concrete, %; D_{10} is the effective particle size, mm; C is the cement dose, kg • m^{-3}; W/C is the water cement ratio.

MIXTURE DESIGN METHOD

Design standard. The composition design of porous concrete should fulfill the demands of porosity, permeability coefficient and strength according to material character with the minimum cement dose. The design effective porosity should be 20%~30%[12~14], the coefficient of permeability shouldn't be less than 1.05cm/s[15], and the strength should fulfill the demands in **Table 9**[16,17].

Table 9. Design compressive strength and flexural tensile strength for porous concrete base

Traffic grade	Extra heavy-duty	Heavy-duty
7d design compressive strength /MPa	5～8	3～5
28d design flexural tensile strength /MPa	1.5～2.5	1.0～2.0

Empirical equation method of mixture ratio design. According to the above orthogonality test results, authors put forward the following empirical equation method of mixture ratio design for porous concrete.

1. Determination of target strength and design porosity

(1) Target strength

According to the preceding mixture ratio design standards, the 7d compressive strength of porous concrete is determined through **Table 8** and the target strength is determined by formula (7).

$$f_{c,o} = 1.15 \cdot f_{c,d} \tag{7}$$

In the formula, $f_{c,o}$ means the 7d target compressive strength, MPa, $f_{c,d}$ means the 7d design compressive strength, MPa.

(2) Design porosity

The design effective porosity of porous concrete is 20%～30%.

2. Determination of aggregate dose

should satisfy the demands of certain porosity and forming high strength after mixed with cement paste. Desirable porous concrete is that the coarse aggregates are interlocked and not interfered after compressed, and there is large friction to form space framework structure. In accordance with Talbol Formula[1)] and foreign experience[9)], authors designed four kinds of gradation listed in **Table 3**.

$$P = 100\left(\frac{d}{D}\right)^n \qquad (1)$$

In the formula, P means the passing percentage of quality through every seive size, %; d means seive size, m; D means the maximum particle size, mm; n means test index.

Table 3. Aggregate gradation of porous concrete

Sieve size /mm	Passing percentage of quality /%			
	Gradation 1	Gradation 2	Gradation 3	Gradation 4
31.5	100	100		
25			100	100
20	76～87	76～87	90～100	
16				25～60
10	0～5	50～71	20～55	
5		0～5	0～10	0～10
2.5			0～5	0～5

Description of aggregate gradation. For aggregate gradation being a kind of distribution, when designing the composition of porous concrete, there should be effective parameters to describe it. Practices have shown [1)] the effective particle size and homogeneity coefficient are effective targets. Furthermore, since porosity is one of the design targets of porous concrete, the percent voids in aggregate can also be used to appraise the gradation indirectly.

1. Effective particle size

Effective particle size D_x is a particle size that the mass passing ratio for those size less than it is x% in sieve curve. When x equates 10, it is also called as Hazen effective size.

Effective size D_{10} can characterize the permeability of materials. When there are more grains with diameter exceeding effective size D_{10}, the material permeability is better.

2. Homogeneity coefficient

Homogeneity coefficient (C_u) is the ratio of particle size with percentage of passing particle 60% to 10%. That is

$$C_u = D_{60} / D_{10} \qquad (2)$$

Homogeneity coefficient characterizes the expanding degree of grain size. It shows the density of material gradation and indicates material permeability indirectly. Study shows [1)] that the combination of big effective particle size and small homogeneity coefficient can get high permeability coefficient. The effective particle size and coefficient of homogeneity of the four kinds of aggregate gradation in **Table 3** are shown in **Table 4**.

Firstly, a kind of aggregate gradation in **Table 3** should be selected according to the materials and porosity and strength demands. Then, the bulk density of the selected aggregate is gotten through vibration method.

The aggregate dose of porous concrete can be gotten through formula (8).

$$G = 0.98 \cdot \rho \quad (8)$$

In the formula, G means aggregate dose of unit volume of porous concrete, kg • m^{-3}, ρ means bulk density of the aggregate, kg • m^{-3}.

3. Determination of cement dose

(1) Determination of cement dose C_1 (kg •m^{-3}) according to target strength

According to formula (3) gotten from preceding orthogonality test, the cement dose of grade 32.5 is shown as formula (9).

$$C_1 = 62.660 + 2.360 D_{10} + 20.000 f_{c,o} \quad (9)$$

To reduce test factors, the paper only studied the relations of strength, porosity and material composition for porous concrete of grade 32.5 cement. When cement of grade 42.5 is adopted, the strength can be converted by the relationship betwen porous concrete of cement grade 32.5 and grade 42.5.

(2) Determination of cement dose C_2 (kg • m^{-3}) according to porosity

According to formula (5), the formula (10) as follows can be drawn.

$$C_2 = 470.761 - 9.174 n_e \quad (10)$$

Comparing the value of C_1 and C_2, if $C_1 > C_2$, the target strength and porosity should be adjusted, and the cement dose should be calculated again according to formula (9) and formula (10) until $C_2 > C_1$, and then the cement dose C (kg • m^{-3}) is determined as C_1.

4. Determination of reasonable water cement ratio and water dose

Since the effective size D_{10} and the cement dose C have been got, the water cement ratio W/C can be drawn from formula (11) as follows.

$$W / C = 0.755 + 0.123 f_{c,o} + 0.015 D_{10} - 6.037 \times 10^{-3} C \quad (11)$$

In actual operation, whether the water cement ratio is reasonable or not can also be judged by experience. If the quantity of water is less, the aggregates will not be parceled by cement paste. However, if the quantity of water is much more, cement paste is too thin to deposit at bottom and either cannot parcel aggregate, which will affect the whole strength and homogeneity of porous concrete. Suitable water content will make cement paste parcel aggregates evenly, with no cement paste dropping, and there being metal lustre on concrete surface. According to experience, the suitable range of water cement ratio is from 0.33 to 0.42.

With the water cement ratio W/C being drawn, the unit water dose W (kg •m^{-3}) can be gotten and shown as formula (12).

$$W = C \cdot (W / C) \quad (12)$$

CONCLUSIONS

(1) The porous concrete should havecertain porosity to fully drain water and certain mechanical strength as well. According to Talbol Formula and foreign experience, four kinds of gradation were designed with the effective size and the homogeneity coefficient being effective targets.

(2) The orthogonality test was designedby studying three factors of cement dose, water cement ratio and aggregate gradation with each choosing four levels, Through variance analysis of the test results, the evidently effective factors to

design targets under different confidence probability were put forward. A series of regression relationships of 7d compressive strength and effective porosity of porous concrete were gotten.

(3) The empirical formula method of mixture ratio design for porous concrete was put forward based on the orthogonality test.

REFERENCES

1) Mu-lian ZHENG. Study on porous concrete permeable base. Doctor degree paper of Chang'an University, 2004.
2) Sparkman, A. 2005. Pervious Concrete Construction. Paper presented at the Pervious Concrete and Parking Area Design Workshop, Omaha, NE.
3) Tamai, M., and M. Yoshida. 2003. Durability of Porous Concrete. Paper presented at the Sixth International Conference on the Durability of Concrete, Thessaloniki, Greece.
4) Tennis, P.D., M.L. Leming, and D.J. Akers. 2004. Pervious Concrete Pavements. Special publication by the Portland Cement Association and the National Ready Mixed Concrete Association.
5) Pacific Southwest Concrete Alliance. 2004. Recommended Specifications for Portland Cement Pervious Concrete Pavements. California Nevada Cement Promotion Council. CD-ROM.
6) Olek, J., W.J. Weiss, N. Neithalath, A. Marolf, E. Sell, and W.D. Thornton. 2003. Development of quiet and durable porous Portland cement concrete paving materials. Final Report SQDH 2003-5. West Lafayette, IN: Purdue University.
7) Florida Concrete and Products Association Inc. 2000. Portland Cement Pervious *Pavement Manual*.
8) Beeldens, A., D. Van Gemert, and C. Caestecker. 2003. Porous Concrete: Laboratory Versus Field Experience. *Proceedings 9th International Symposium on Concrete Roads*. Istanbul, Turkey.
9) FHWA. Guidelines for design of subsurface drainage systems for highway structural sections. Washington, D. C: FHWA, 1973.
10) Qing-ke JI, Zu-kang YAO. Mix design procedure of porous cement treated macadam. Journal of Tongji University, 2003, 31(2): 161-165.
11) Nai-qian FENG. Applied concrete. Science Publishing Company, 2001.
12) Hong-bin XIE, Zu-kang YAO. Permeability of asphalt treated permeable base materials. China Journal of Highway and Transport, 2003, 13(2): 20-23.
13) Ghafoori. N. and S.Duta. Development of no-fines concrete pavement applications. Journal of Transportation Engineering，1995，121（3）: 282-288.
14) Guo-qiang LI, Xue-jun DENG. Research on critical porosity of pavement porous course. China Journal of Highway and Transport, 1996, 9(2): 28-33.
15) JTJ 018-97, Specifications of drainage design for highways.
16) JTJ 034-2000, Technical specifications for construction of highway raodbase.
17) Wei LIU, Research on structure design of cement concrete pavement with lean concrete base. Master degree paper of Chang'an University, 2003.