論文 Laboratory Research on Some Properties of Previous Concrete and Its Applicability to Control Stormwater Run-off

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ABSTRACT: This study investigates the effects of mixture proportions on some properties of "no-fines" previous concrete and evaluates its applicability to control stormwater run-off. Main findings are: a) strengths of previous concrete depend not only on its proportions but also on the curing conditions, b) for any cement content, there is a very narrow optimum range of water-cement ratio that leads to maximum strength, c) the secant modulus of elasticity can be rapidly estimated using ACI 318 developed equation, and d) previous concrete with 15 to 30% voids can practically control the stormwater run-off.
KEYWORDS: "no-fines" previous concrete, mixture proportions, curing methods, unit weight, void content, strength, secant modulus of elasticity, percolation rate, run-off control.

1. INTRODUCTION

Previous concrete can be easily produced. The substantially reduction or total elimination of fine aggregate portions from the concrete matrix is the mostly used procedure to obtain previous concrete[1]. As an Environmentally Friendly material, the "no-fines" previous concrete has become increasingly popular. It is known as EnviroCrete, EcoCrete, VegCrete, GrassCrete, Green concrete, DrainCrete, Permeacon and more generally as Porous Concrete.

Even though it is suitable for various environmental applications[1], the influence of mixture proportions on some properties of this previous concrete is not widely investigated[2]. Consequently, the present study was carried out to investigate the effects of cement content, water-cement ratio, unit weight and void content on the strength, modulus of elasticity and percolation properties of "no-fines" previous concrete. Moreover, the applicability of stormwater run-off control by "no-fines" previous concrete was examined.

2. EXPERIMENTAL WORK

2.1 MATERIALS

Three different crushed coarse aggregates 5~10mm, 10~15mm and 5~20mm were used to produce "no-fines" previous concrete. Ordinary portland cement of specific gravity of 3.15 and blaine of 3290cm^2/g was used to bind the coarse aggregates. A graft copolymer with specific gravity of 1.10 ± 0.3 and solid content of 30% was used as superplasticizer. The required data on coarse aggregates (mainly: specific gravity in saturated surface-dry condition, percentage of water absorption and bulk density) were determined according to the relevant Japanese Industrial Standard.

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2.2 MIXTURE PROPORTIONS AND SPECIMENS CASTING

Table 1 Conditions of mixture proportions

Min. Void content (%)	15
Min. Percolation (cm/s)	0.1
Crushed aggregate	3 ≠ gradations
Water / Cement (%)	25 ~ 55
Cement content (kg/m^3)	154 ~ 485
Plasticiser / Cement (%)	0 ~ 1.0

The mixture proportions prerequisite were set to a minimum void content of 15% and a minimum water percolation rate of 0.1cm/s. The use of easily available aggregates and ordinary mixing techniques and equipment was considered rudiment. The aggregate content was kept constant to that of its saturated surface dry bulk density and the cement content was changed. The water-cement ratio ranged between 25% and 55%. Table 1 summarizes the conditions of mixture proportions. The concrete was mixed in a pan-type forced circulating 50 liters' mixer operated at 75% capacity for nearly 3 minutes. Care was taken to add just enough plastisiser[3] during the mixing to produce a sheen to the cement paste coating on each particle of coarse aggregate so that, wherever any two particles touched, a meniscus of cement paste was formed of considerable great area than the actual contact surfaces. It was reported that cement paste at the points of contact between aggregate particles provides bonding, while that coating open surfaces contributes little to the strength development[4]. Consistency was visually examined. It was insured that cement paste coating the aggregate is neither too dry nor so wet. Concrete was placed in the molds in layers of about 10cm and was carefully light hand rammed to ensure its uniform distribution and to avoid aggregate fracture. Rectangular wooden tamper was used to provide for uniform compaction in the corners of beams. Exposed surfaces were finished with trowel. Test specimens were kept under wet cover in the laboratory for 24 hours. Later, they were demolded and subjected to 3 different curing conditions until required for testing. According to the first compression test results, curing in water at 20 ± 2°C was acknowledged and adopted for the remaining part of this study.

2.3 TESTING ITEMS AND PROCEDURES

Void content that accounts the total volume of voids for the migration of fluids within the hardened concrete was assumed to be a very important factor in this research. Its values were calculated following the procedure proposed by the JCI Eco-Concrete Research Committee[2].

Compressive strength tests were performed according to the JIS A 1108 on cylindrical specimens of 10 x 20cm up to an age of 91 days. Double face capping with sulfur was used. During compression test, the displacement of each specimen was measured using a compressometer and the secant modulus of elasticity was calculated according to JSCE-G502. To reduce the within-batch variation for secant modulus of elasticity due to the honeycomb structure of "no-fines" previous concrete, small PVC arcs were putted in all contact points between compressometer and specimen.

Flexural strength tests were made according to the JIS A 1106 up to an age of 91 days on prismatic specimens 10 x 10 x 38cm. Good contact between the contact surface of testing apparatus and surface of specimens was assured by gypsum.

Percolation rate was measured by using a falling head permeameter not only due to the fact that this procedure was proved fast, simple and useful for comparative studies[5] but also because there is no standard laboratory test for permeability of "no-fines" previous concrete. Within this experiment the time required for water head to drop by 10cm from a higher level of nearly 18cm, was measured to determine the percolation rate.

3. RESULTS AND DISCUSSION

3.1 EFFECT OF CURING PROCEDURES ON COMPRESSIVE STRENGTH

The strengths of previous concrete depend not only on its proportions, as it will be illustrated below, but also on its curing conditions. Twenty-seven test specimens were made with 5~20mm crushed aggregate and cement content of 318kg/m^3. They were cured under different without any special precautions and in water at 20 ± 2°C; and tested for compressive strength at the ages of 7, 28 and 91 days. Results are shown in Fig.1. The compressive strength of the air cured concrete reached only 54%, 78% and 77% of the compressive strength of similar concrete cured at 20 ± 2°C and 80 ± 10% R. H. for 7, 28, and 91 days respectively. However, water cured concrete showed a slight improvement on its compressive strength. For air cured concrete, the cement paste failed to hold the aggregate particles together and the low strength was presumably due to the incomplete hydration of the thin layer of cement paste coating the aggregate particles. Consequently, water curing is acknowledged and recommended to achieve a better strength.

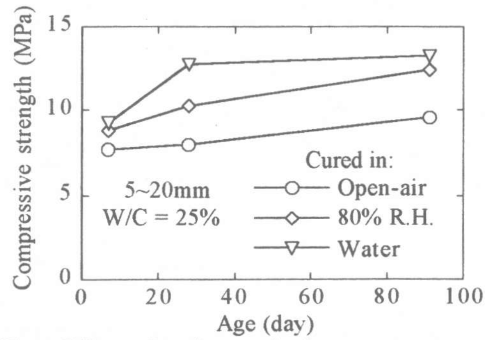

Fig.1 Effect of curing methods on compressive strength of previous concrete made with crushed aggregate 5-20mm

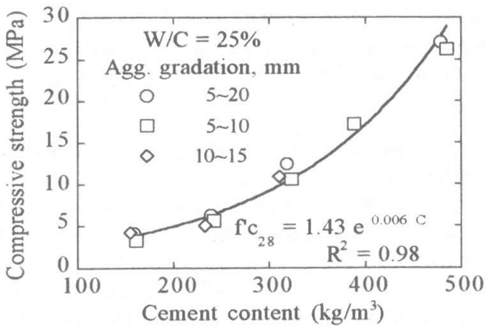

Fig.2 Relationship between compressive strength and cement content.

3.2 EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH

Fig.2 depicts a relationship between compressive strength of "no-fines" previous concrete tested after 28 days of water curing and cement content. The increment in compressive strength is not proportional to that in the cement content. Similar results are reported elsewhere[6]. This comes to confirm that cement paste at the points of contact between aggregate particles provides bonding, while that coating open surfaces contributes little to the strength development[4]. For rich "no-fines" previous concrete, most of the cylinder breaks exhibited the classic conical shape indicative of the uniaxial loading. In general, the breaks occurred through the aggregate particles even at early stages of curing. However no breaks occurred through the particles for lean "no-fines" previous concrete.

3.3 EFFECT OF WATER-CEMENT RATIO ON COMPRESSIVE STRENGTH

For 3 different cement contents 318, 239, and 159kg/m^3 and 5~20mm crushed aggregate, "no-fines" previous concrete was made with water-cement ratios varying from 55 to 25%. Fig.3 shows the compressive strength of this concrete and cement paste specimens tested for compressive strength at the ages 7, 28, and 91 days in relation to the water-cement ratio. If the traditional Abrams law does hold for cement paste mixtures, for the other three series of "no-fines" previous concrete mixtures, although strength increases with age as expected, the increase in strength with a corresponding decrease in water-cement ratio is not proportional to that of cement paste mixes. Consequently, unlike conventional concrete in which strength is primarily controlled by the traditional water-cement ratio law, the strength of "no-fines" previous concrete is governed simultaneously by water-cement ratio and cement content. Therefore for any cement content, there is a very narrow optimum range of water-cement ratio that facilitates the migration of the paste toward the points of contact and thus leads to maximum strength.

3.4 EFFECT OF PREVIOUS CONCRETE'S UNIT WEIGHT ON COMPRESSIVE STRENGTH

Fig.4 shows that the compressive strength of "no-fines" previous concrete with a water- cement ratio of 25% depends mainly on its unit weight. However, when data represented in Fig.3 were included, the relationship between compressive strength and unit weight was expressed as:

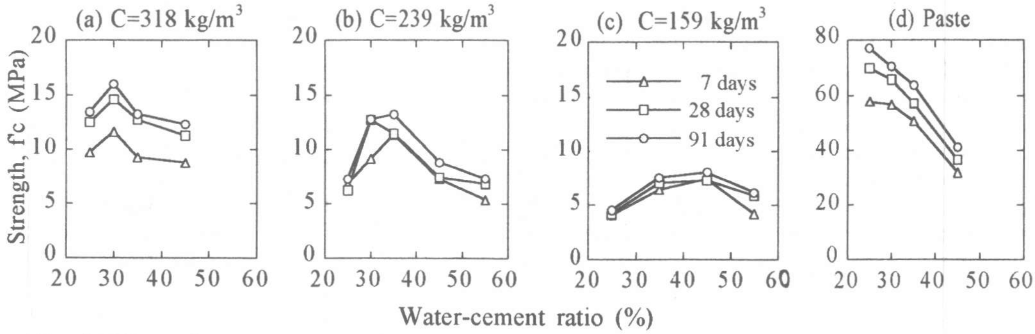

Fig. 3 Effect of water-cement ratio, cement content and age on compressive strength

$f'c_{28} = 0.0429$ UW − 70 with an R^2 value of 0.65. Indeed this drop in R^2 value makes absolutely clear that water-cement ratio plays a considerable role in determining the strength of this kind of concrete.

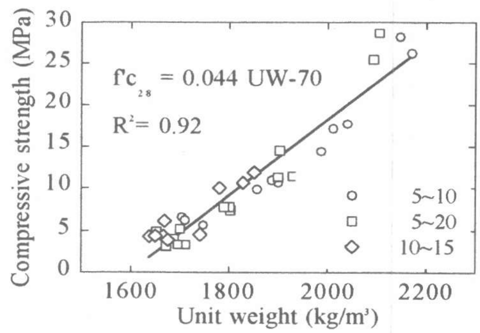

Fig.4 Relationship between compressive strength and unit weight of "no-fines" previous concrete

3.5 EFFECT OF UNIT WEIGHT ON VOID CONTENT

The unit weight of the light hand rammed "no-fines" previous concrete specimens, as shown in Fig.5, varied from 1638 to 2170kg/m^3. The most adequate equation for void content - unit weight relationship was found to be linear and given by: Vct = 107.36 − 0.043 UW.

A 100kg/m^3 increase in unit weight, governed by the cement content, reduced the void content by about 4.3%.

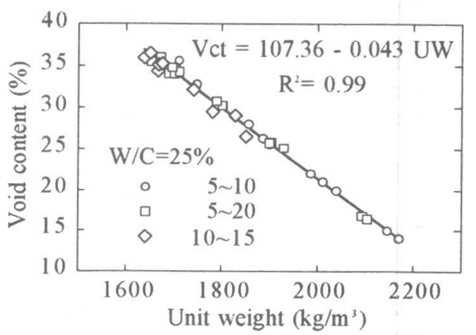

Fig.5 Effect of unit weight of "no-fines" previous concrete on the void content

3.6 SECANT MODULUS OF ELASTICITY

Fig. 6 depicts an example of stress-strain relationship for "no-fines" previous concrete made with 5~10mm crushed aggregate and tested after 28 days of water curing. It shows that strain quantity is proportional to maximum stress. Strain increases with any increment of maximum stress and decrease of void content[7]. The secant modulus of elasticity of "no-fines" previous concrete, given by the slope of a line drawn between two points on the stress-strain curve and corresponding to a longitudinal strain of 50μ to the point that corresponds to 1/3 of the maximum stress, was calculated according to JSCE-G502. The void content affects the secant modulus of elasticity significantly. An increase in void content by 2% decreases the secant modulus of elasticity by about 1 GPa. Fig.7 shows that the secant modulus of elasticity can be expressed as function of "no-fines" previous concrete unit weight and its compressive strength. Regression analysis afforded to the following equation: $E = 1.51 + 0.043\ UW^{1.54}\ fc_{28}^{(1/3)}$ with an R^2 value of 0.90. In addition, the experimental values are relatively close to that calculated using ACI 318 developed equation ($E = 0.043\ UW^{1.5}\ fc_{28}^{0.5}$) and therefore, ACI 318 developed equation can be used to rapidly estimate the secant modulus of elasticity, whenever it is necessary, due to experimental difficulties to measure it.

3.7 EFFECT OF VOID CONTENT ON COMPRESSIVE, FLEXURAL STRENGTH AND WATER PERCOLATION

Relationships between flexural, compressive strength and total void content, water percolation and continuous void content for "no-fines" previous concrete made with crushed aggregate are reported in Fig.8. Both, flexural and compressive strength increased with any decrease in void content. The ratio of flexural strength to compressive strength varied from 1/3 to 1/6.

Within this study, for any continuous void content the percolation rate exceeded significantly the minimum required mixture proportions percolation set to 0.1cm/s. Therefore previous concrete with a total void content between 15 and 30% may be efficiently used as permeable concrete or rain-store. As for example, "no-fines" previous concrete with 25% void content might have a flexural strength exceeding 3.5MPa (a value exceeding a requirement of 2.9MPa for interlocking block pavement[8]) and a percolation rate of more than 1cm/s.

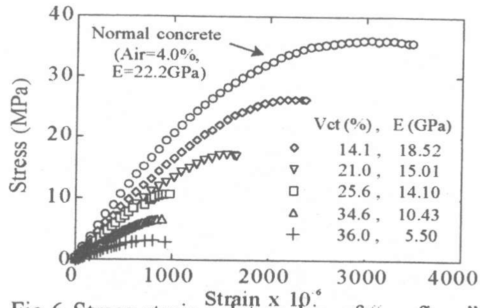

Fig.6 Stress-strain relationship of "no-fines" previous concrete made with 5-10mm crushed aggregate

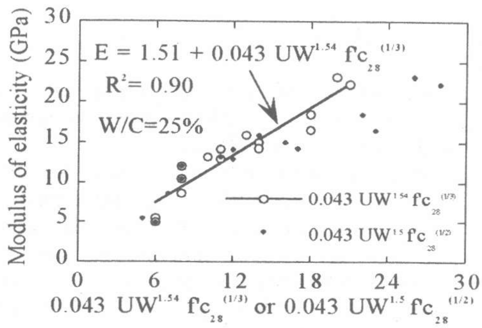

Fig.7 Modulus of elasticity of "no-fines" previous concrete made with 5~10mm crushed aggregate

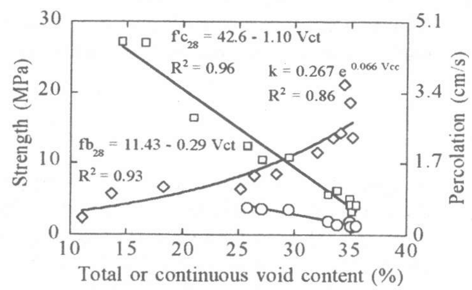

Fig.8 Relationship between compressive strength, flexural strength, percoltion rate and void content

3.8 STORMWATER RUN-OFF CONTROL

During any given rainfall event, the main controls upon the amount of percolation and run-off are the potential percolation rate of the land-surface and the intensity of the rainfall. Asphalt pavements, concrete buildings and other impervious materials, have covered the surfaces of rapidly civilized cities. This significantly increase in land coverage development causes not only a stormwater run-off and prevents the recharge of ground water[9] but also downstream flooding and pollution of surface waters[10]. Stormwater run-off and lack of percolation of impermeable surfaces are harmful to water quality and all living things[11].

Photo1 shows that water filters rapidly through the previous concrete to a secondary filter layer in the ground. This allows for natural recharge of groundwater and pollution retention. Fig.9 compares the run-off coefficient for different types and thickness of concrete pavement. The data plotted here are calculated for previous concrete with 25% void content placed on a 15cm crusher-run layer containing 10% voids. The two layers are supposed laid over a native soil with a percolation rate of 10^{-5}cm/s. Thickness of "no-fines" previous concrete for parking area or walk space can be calculated according to pavement design regulations. In comparison with impermeable asphalt pavement, previous concrete is good to control stormwater run-off. Furthermore, as illustrates clearly in Fig.9, the thickness of "no-fines" previous concrete affects the flood run-off. The thicker the concrete is the lower the run-off coefficient is. Also for same thickness, the higher the void content is the lower the run-off coefficient is. Consequently the determination of the thickness of previous concrete should satisfy not only pavement design regulations but also consider the urban meteology conditions and percolation rate of native soil.

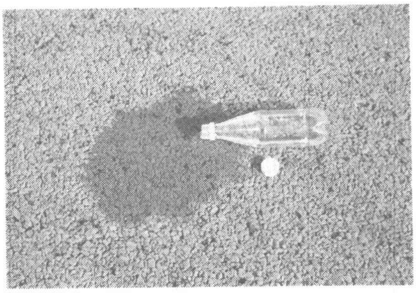

Photo 1 Water percolates quickly into "no-fines" previous concrete

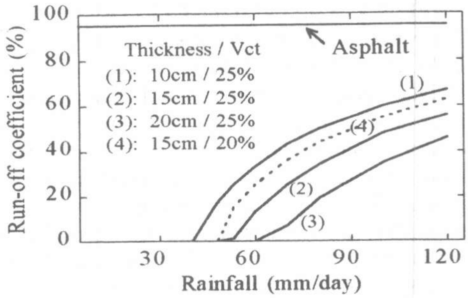

Fig.9 Effect of previous concrete thickness and void content on flood run-off

4. CONCLUSIONS

The present study investigating the effect of mixture proportions on some non-widely investigated properties of "no-fines" previous concrete and its use for stormwater run-off control led up to the following conclusions:

1) The strengths of previous concrete depend not only on its proportions but also on its curing conditions; water curing is recommended to achieve a better strength.
2) The compressive strength, which depends mainly on concrete unit weight, is not proportional to the cement content. For any cement content, there is a very narrow optimum range of water-cement ratio that facilitates the migration of the paste toward the points of contact and thus leads to maximum strength.
3) An increase of 100 kg/m^3 in unit weight reduces the void content by about 4.3%.
4) The secant modulus of elasticity decreases by about 1 GPa for each 2% increase in void content and can be rapidly estimated using ACI 318 developed equation.
5) Previous concrete with 15 to 30% voids can successfully be used to reduce stormwater run-off. Furthermore, the thickness determination of previous concrete should fulfill the pavement design regulations and the urban meteology conditions.

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