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Frost Resistance of Pervious Concrete with Different Freezing and Thawing Tests

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ABSTRACT

Pervious concrete has large continuous voids of 20-30 % by volume, and has some particular properties (i.e. high-permeability, purification, vegetation, etc). Pervious concrete is attractive as new environmental material and has begun to be applied for the river bank protection and road pavement in Japan. The object of this study is to investigate the frost resistance of pervious concrete as environmental materials. This investigation attempts to address this concern by comparing 3 kinds of specified freezing and thawing tests methods (ASTM C 666 procedure A, B methods and RILEM CIF). RILEM CIF test is different from ASTM C 666 method in water absorption, rate of cooling, length of freezing and thawing period, and number of freezing and thawing cycles. Test result of ASTM C 666 procedure A method, which is widely used for evaluating the frost resistance of concrete, showed extremely low durability of pervious concrete. Because of the low strength and the high porosity due to large void structure, frost resistance of pervious concrete seems to be lower than that of conventional concrete. However, result of RILEM CIF test showed adequate frost resistance. From these test results, it is found that difference of freezing and thawing test has influence on the evaluation of frost resistance. In addition, this study has conducted in situ exposure test for 5 years. Some pervious concrete blocks have been applied for river bank protection of Hokkaido Naie river in Japan, which resembles 70-80 cycles of freezing and thawing action annualy. Frost damage of these blocks by ultrasonic velocity measurement were evalutated to be in a slight degree. From these tests, a total of 350-400 cycles of natural freezing and thawing action showed a similar damage trend as RILEM CIF test and a significant difference with ASTM C 666 procedure A method is observed.

KEYWORDS

Pervious concrete, Frost resistance, ASTM C666, RILEM CIF, Exposure test

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1 INTRODUCTION

In recent years, necessity of the environmental materials for sustanable development is increasing over the world, and pervious concrete has been proposed to be used as such material. The characteristic of pervious concrete has a large continuous void strcure, which accounts for about 20-30 % of the whole volume. Pervious concrete can have a high permeability (about 1.0 cm/sec) and is generally applied for road pavement. This type of concrete, which has large void structure, came from “No-Fines Concrete”. According to Malhotra, No-fines concrete had been used in Europe and the United Kingdom since 1930s for building of single story and multistory. In recent Japan, this type of concrete is sometimes called as “Porous concrete”, and has begun to gain attention as a promising environmental material. The idea is that the large continuous void structure can give pervious concrete the ability of high permeability, purification, and vegetation. Pervious concrete has begun to be applied for the protection of river dam and further to road pavement.

It is necessary to confirm the frost resistance when pervious concrete is used in cold region. Many reports investigated the environmental functions of pervious concrete [JSCE, 2002]. However, there are few reports of the frost resistance. Frost resistance of pervious concrete has been investigated by several freezing and thawing tests method [M. Sugiyama, 2002 ; Obi and Taguchi, 2004]. The results were not clearly in agreement with in situ exposure condition. Therefore frost resistance of pervious concrete should be evaluated by an specified freezing and thawing test methods. This study attempts to address this concerns by comparing the test result of RILEM CIF test method (“RILEM Recommendation TC176-IDC”), and that of ASTM C666 procedure A and procedure B methods (“Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing”).

It is necessary to conduct in situ exposure test as well as some laboratry tests. This investigation compared the result of in situ exposure test at Hokkaido Naie River in Japan with that of laboratory freezing and thawing tests.

The results of this study provide additional evidence to support the need in obtaining a viable freezing and thawing method and applicable to pervious concrete as environmental material.

2 MATERIALS AND MIXTURE PROPORTION

The mixture proportion in this study is shown in Table 1. The test specimen consisted of 3 types. Design values for the void ratio is set to 20%. Water cement ratio are set to about 23.5 % and 24 %. The matrix constituents of pervious concrete consisted of ordinarily portland cement (C), fine aggregate (S), coarse aggregate (G6 or G7), tap water (W) and some chemical admixtures. Particle size of G6 is 5-13 mm with specific gravity of 2.63. Particle size of G7 of 2.5-5 mm with specific gravity is 2.62. For NR6, a high viscosity agent was added. All specimen contained air-entraining and high-range water-reducing admixture (SP).

Table1. Mixture proportion.

	Void	W/C	Unit content (kg/m^3)						
	(%)	(%)	W	C	S	G6	G7	Ad	SP
NR6	20	24	99	413		1550		8.3	3.1
PG6	20	23.5	80	340	106	1503			3.4
PG7	20	23.5	80	340	172		1431		3.4

3 EXPERIMENTAL PROCEDURES

3.1 Freezing and Thawing Test

The frost resistance of pervious concrete was determined using the specifications of ASTM C 666 procedure A method and procedure B method (“Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing”), and RILEM CIF test (“RILEM Recommendation TC176-IDC”). Some of important details of three procedures are given in Table 2. As shown in this table, ASTM C 666 is a more severe testing method than CIF test in relation to rate of cooling, length of freezing and thawing period, and number of cycles. A brief description of each test method is provided in the next paragraphs.

Table 2. Test details of ASTM C 666 and RILEM CIF tests methods.

	ASTM C 666 test (procedure A)	ASTM C 666 test (procedure B)	RILEM CIF test
Number of cycles (test period)	300 6 cycles/day (50 days)	300 6 cycles/day (50 days)	56 2 cycles/day (28 days)
Freezing period Lowest temperature	2.75 hr -17.8 C	2.75 hr -17.8 C	7 hr -20 C
Cooling rate	14.4 deg C/hr	14.4 deg C/hr	10 deg C/hr
Thawing period Highest temperature	1 hr 4.4 C	1 hr 4.4 C	5 hr 20 C
Water absorption condition	Entire surfaces	Entire surfaces (only thawing phase)	Only 1 test surface
Evaluation method	Fundamental transverse frequency	Fundamental transverse frequency	Ultrasonic pulse velocity

3.1.1. ASTM C 666 Tests (Procedure A and Procedure B)
Specimens were presoaked in water for 24 hr before starting of freezing and thawing test. For Procedure A, each specimen is completely surrounded by not less than 1 mm nor more than 3 mm of water at all times while it is being subjected to freezing and thawing cycles. For Procedure B, each specimen is completely surrounded by air during the freezing phase of the cycle and by water during the thawing phase. Freezing and thawing test continued on each specimen until it has been subjected to 300 cycles or until it is impossible to measure fundamental transverse frequency. In this test methods, relative dynamic modulus of elasticity is used to evaluate frost damage.

3.1.2 RILEM CIF Test
Specimens were placed in the test containers on 10 mm high spacers with the tested surface underneath. Subsequently, the test liquid was filled into the container to a height of 15 mm. Pre-saturation of test liquid by capillary suction was conducted for 7 days at a temperature of 20 deg C before starting freezing and thawing test. During capillary suction, the liquid level was checked and adjusted. To evaluate frost damage, ultrasonic pulse velocity (UPV) was measured. The transducers were mounted on the sides of the container so that the transit path axis should be parallel and 35mm from the test surface.

3.2 In Situ Exposure Test

Pervious concrete blocks for river protection were exposed at Hokkaido Naie-river in Japan, which has severe environment of freezing and thawing action. The freezing and thawing cycles of this site is about 70 - 80 cycles in a year. The blocks were similar mixture of NR6 in Table 1. To evaluate frost damage, ultrasonic pulse velocity had been measured for 5 years. Consequently a total of 350-400 freezing and thawing cycles were considered to be occured during the investigartion.

4 RESULT AND DISCUSSION

4.1 Frost Resistance with ASTM C 666 Test Procedure A Method

Relative dynamic modulus of elasticity conducted by ASTM C666 procedure A method is shown in Figure 1. As shown in this figure, relative dynamic modulus of elasticity of PG6 and PG7 decreased to about 50 % and 80 % with the same freezing and thawing cycles. Relative dynamic modulus of elasticity of NR6 decreased sharply and specimens of NR6 failed before 30 freezing and thawing cycles. From these results, pervious concrete failed at early freezing and thawing cycles. It showed extremely low durability of pervious concrete with regards to ASTM C666 procedure A method. Because of the low strength and the high porosity, the frost resistance of pervious concrete seems to be lower than that of conventional concrete. In other words, this type of test method seems to bring the pervious concrete in significant disadvantage.

The frost resistance of NR6 was lower than that of PG6 and PG7. One of major differences between NR6 and PG6 is without/with fine aggregate. This indicated that addition of fine aggregate improves the frost resistance. As can be seen on PG7 and PG6 in this figure, the resistance to freezing and thawing improved with a decrease in the particle size of coarse aggregate. Figure 2 shows the typical fracture patterns of NR6 conducted by ASTM C666 procedure A method. The failure of specimen could be attributed to the formation and rapid propagation of large cracks. These cracks originated from stress of ice formation that occured in large continuous voids (greater than 1 mm in diameter). As particle size of coarse aggregate is large, large continuous void size grows larger. Therefore frost resistance of PG6 and NR6 were lower than that of PG7.

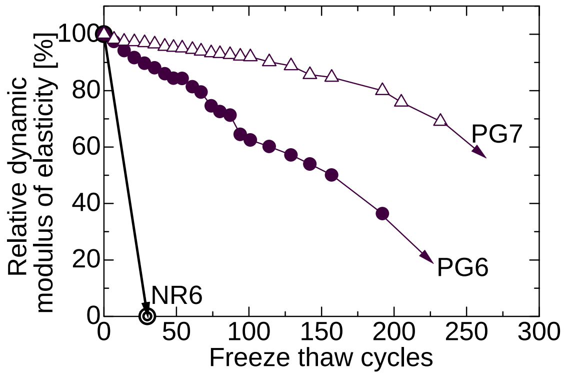

Figure 1. Relative dynamic modulus of elasticity (ASTM C666 procedure A).

Figure 2. Typical fracture patterns after ASTM C666 test procedure A (NR6).

4.2 Frost Resistance with ASTM C 666 Test Procedure B Method

Figure 3 shows relative dynamic modulus of elasticity under ASTM C666 procedure B method. As shown in this figure, relative dynamic modulus of elasticity decreased to about 80 % gradually with additional cycles of freezing and thawing. Comparing with procedure A method, the influence of different particle size and usage of fine aggregate can not be confirmed. Most specimens showed similar decreasing tendency.

Figure 4 shows typical fracture patterns of NR6 by ASTM C666 procedure B. The corner of specimen dropped out with fracture patterns shown in Figure 4, making impossible to measure the fundamental transverse frequency. This phenomenon originated from frost damage of a slight cement paste matrix of pervious concrete. As micro crack developed in cement paste matrix, more water could enter the specimens and freeze, thus further accelerating the rate of crack propagation and eventually leading to spalling and crumbling on the corner of specimen.

4.3 Frost Resistance by RILEM CIF Test

Relative ultrasonic pulse velocity under RILEM CIF test is shown in Figure 5. The result of RILEM CIF test was different from that of ASTM C 666 procedure A and B methods. Relative ultrasonic pulse velocity remained on the same level with additional cycles of freezing and thawing. Therefore deterioration at all specimens of this study was evaluated as a slight frost damage.

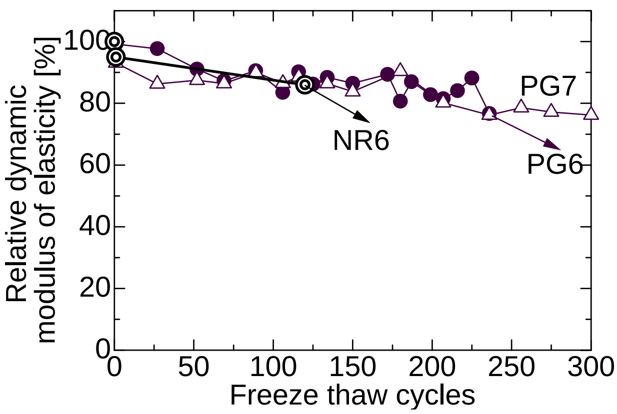

Figure 3. Relative dynamic modulus of elasticity (ASTM C666 procedure B).

Figure 4. Typical fracture patterns after ASTM C666 test procedure B (NR6).

Figure 6 shows a typical fracture patterns after RILEM CIF. In addition, after finishing freezing and thawing test (56 cycles), a little scaling of cement paste without coarse aggregate was found,.and deterioration on tested surface was a slight degree.

The main objective of this investigation is to compare ASTM C 666 procedure A method, procedure B method and RILEM CIF test. Frost resistance of pervious concrete seems to be lower than that of conventional concrete. From the result of ASTM C 666 procedure A method in this study, frost resistance of pervious concrete was evaluated to have a low durability with agrees well with previous research. However, results of RILEM CIF test showed pervious concrete has adequate frost resistance without causing severe scaling and spalling. From these results, the difference of freezing and thawing tests influenced the evaluation of frost resistance on pervious concrete.

4.4 In Situ Exposure Test

Figure 7 presents the change of relative ultrasonic pulse velocity in Naie River blocks for 5 years. Total of 6 blocks (No 1, 2, 3, 9, 13, 24) were measured. As shown in this figure, the ultrasonic pulse velocity for 5 years showed almost a constant valve. The relative ultrasonic pulse velocity of all blocks showed higher than 90 %. These results was found to be that there is no significant frost damage. In addition, the blocks surface seemed to show no deterioration, without spalling nor large crack.

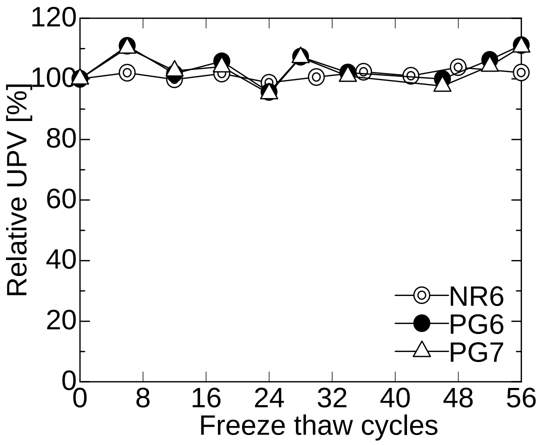

Figure 5. Relative ultrasonic pulse velocity under RILEM CIF

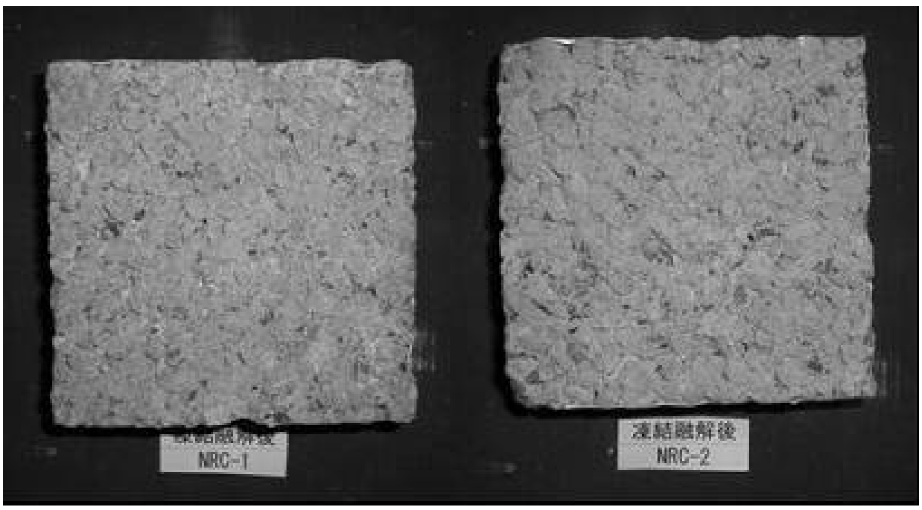

Figure 6. Typical fracture patterns after RILEM CIF (NR6)

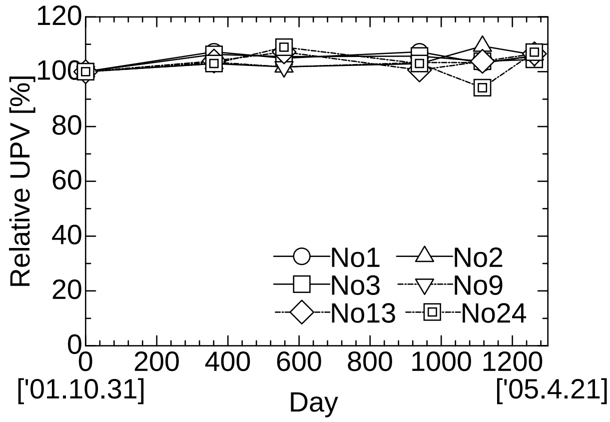

Figure 7 Relative ultrasonic pulse velocity in Naie River blocks.

As already mentioned, more than 70 cycles of freezing and thawing per year were affected to the concrete in situ exposure test. This indicates that more than 350 cycles of freezing and thawing action during the whole 5 years doesn't correlate with the result of ASTM C 666 procedure A method but it shows better correlation with the one of procedure B method and RILEM CIF test.

5 CONCLUSION

Based on the results of shis study, the following conclusions can be drawn:

1. By ASTM C666 procedure A method, relative dynamic modulus of elasticity decreased rapidly and the failure of specimen was attributed to the formation and rapid propagation of large crack. These cracks originated from stress of ice formation which occured in large continuous voids. Frost resistance of pervious concrete may be improved by using small particle size (G7) and fine aggregate in this investigation.

2. By ASTM C666 procedure B method, relative dynamic modulus of elasticity decreased to about 80 % gradually with additional freezing and thawing cycles. This phenomenon originated from frost damage of a slight cement paste matrix of pervious concrete in rapid freezing and thawing actions. The severe fracture patterns observed on ASTM C666 procedure A method did not occured.

3. By RILEM CIF, all specimens showed no clear declination of relative ultrasonic velocity. After freezing and thawing test, surface damage with large cracks was not found. Similar specimens tested in the rapid freezing and thawing environment of ASTM C 666 displayed a far greater degree of frost damage. This phenomenon seemed to originate from the cooling rate and large void strcture which is a characteristic of pervious conrete.

4. The result of in situ exposure test showed little frost damage for five years. The change in relative ultrasonic velocity indicated that freezing and thawing action of in situ exposure test didn't correlate with that of ASTM C 666 procedure A method, but showed better correlation with procedure B method and RILEM CIF test. Total of 350-400 cycles of natural freezing and thawing action showed a similar trend as RILEM CIF test but a significant difference with ASTM C 666 procedure A method.

5. The resistance of pervious concrete to freezing and thawing seems to be considered to be lower than conventional concrete. It is because porous concrete has continuous void structure into which water can permeate during freezing and thawing. However, it is found that the pervious concrete has adequate frost resistance by results of RILEM CIF and in situ exposure test.

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