EVALUATION OF FREEZE-THAW RESISTANCE OF CONCRETE PAVING BLOCKS

A. KARASAWA, H. FUJITA, E. SAKAI,T. TAKAMORI, T. SHIROISHI

A. KARASAWA: Research & Development Center, TAIHEIYO CEMENT CORPORATION, 2-4-2, Osaku, Sakurashi, Chiba Prefecture, 285-8655, JAPAN, Tel: +81 43 498-3894, Fax:+81 43 498 3849, Email: akihiko_karasawa@taiheiyo-cement.co.jp
H. FUJITA: Research & Development Center, TAIHEIYO CEMENT CORPORATION
E. SAKAI: Research & Development Center, TAIHEIYO CEMENT CORPORATION
T. TAKAMORI: TAIHEIYO CEMENT CONCRETE PAVING BLOCK ASSOCIATION
T. SHIROISHI: TAIHEIYO CEMENT CONCRETE PAVING BLOCK ASSOCIATION

SUMMARY

Recently in Japan, demand for environment-friendly pavement blocks such as permeable blocks, water-retentive blocks, and blocks made of recycled material has increased. When these blocks are used in a cold climate area, clients often request an evaluation of the blocks' durability against freeze-thaw cycles, even though no damage due to freeze-thaw effects has ever been reported in Japan with either standard blocks (flexural strength of 5 N/mm^2 or higher) or permeable blocks (flexural strength of 3 N/mm^2 or higher). [1]

There is currently no standard method for testing the freeze-thaw resistance of concrete paving block in Japan. Thus, a test based on JIS A 1148-2001 "Method of test for resistance of concrete to freezing and thawing" is usually used for provisionally testing paving blocks. [2] This JIS method conforms to ASTM C 666-1997 "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing." However, it has been pointed out that this JIS method is inappropriate for evaluating the freeze-thaw resistance of concrete blocks because it is intended for concrete slabs, although no specific problem regarding this difference has been identified.

Against this backdrop, this paper identifies the problems in the JIS 1148-2001 test method by evaluating the freeze-thaw resistance of various concrete paving blocks obtained with this method. The paper also reports the results of measuring the surface and inside temperatures of various concrete blocks installed in a cold climate area. This field test was conducted specifically to collect data for further studying a new freeze-thaw test method suitable for evaluating the freeze-thaw resistance of concrete paving blocks. Lastly, the paper reviews various freeze-thaw standard test methods for concrete blocks in other countries, as well as the results of freeze-thaw resistance for various concrete paving blocks using some of those test methods.

1. JIS A 1148-2001 TESTS

1.1 Overview of tests

The concrete mix proportions of test pieces are listed in Table 1. These proportions are of the dry cast concrete used for standard blocks, permeable blocks, and water-retentive blocks. The unit cement content of 400 kg/m^3, which is typical for actual products, was used for all mix proportions. Two different unit water contents were used for each proportion for the purpose of controlling air content and flexural strength. The Japanese quality standard for interlocking blocks requires flexural strength to be 5 N/mm^2 or higher for standard blocks and 3 N/mm^2 or higher for both permeable blocks and water-retentive blocks. For the mix proportions of water-retentive blocks, autoclaved lightweight aerated concrete material (ALC) crushed to 4.0 mm to 0.8 mm grain size was added as the water-retaining material. The test pieces were produced using a compact dry cast machine, which is capable of producing test blocks under the same vibration conditions as the actual products.

The size and physical characteristics of the test pieces are shown in Table 2. The test pieces were produced in two sizes: the JIS size of 100 × 100 × 400 (mm) and the actual block size of 100 × 200 × 80 (mm).

For the block-size test pieces, flexural strength tests were performed in accordance with JASS 7 M101 “Flexural strength test methods for interlocking blocks. [3] ” For JIS-size test pieces, JIS A 1106 “Method of test for flexural strength of concrete” was applied. [4] Test pieces were air-cured in an environment of 20°C and 60% RH for 14 days before testing.

Freeze-thaw tests were performed according to “Underwater freeze-thaw tests” (Method A) and “Atmospheric-freeze, underwater-thaw tests” (Method B) of JIS A 1148 “Methods of testing for resistance of concrete to freezing and thawing.” Test pieces were air-cured in an environment of 20°C and 60% RH for 14 days before testing.

Table 1 Mix proportion of test pieces

Type	No.	W/C (%)	Unit content (kg/m^3) W	OPC[1)]	G1[2)]	G2[3)]	S	AE[4)]	ALC	Unit content (kg/m^3)	Remark
Standard	1	35.3	141	400	479	479	957	-	-	2456	G1:G2:S = 25:25:50 (wt.%)
	2	25.3	101	400	505	505	1010	-	-	2521	
Permeable	3	20.3	81	400	-	1665	408	4.000	-	2559	
	4	19.0	76	400	-	1676	411	4.000	-	2567	
W-retentive	5	34.0	136	400	292	292	1050	-	138	2309	s/a = 70% ALC = (G1+G2+S) x 15 (vol.%)
	6	31.5	126	400	296	296	1065	-	140	2323	

1) Ordinary Portland cement
2) Crushed stone of grain size 5 to 13 mm
3) Crushed stone of grain size 2.5 to 5 mm
4) Polycarboxylic acid type AE water reducing agent

Table 2 Size and physical characteristics of test pieces

Type	Size	No.	Air content (%)	Flexural strength (N/mm^2)
Standard	JIS size (100 x 100 x 400 mm)	1	1.5	6.06
		2	13.5	3.98
	Block size (100 x 200 x 80 mm)	1	2.5	7.29
		2	13.2	4.15
Permeable	JIS size (100 x 100 x 400 mm)	3	23.6	3.35
		4	25.1	2.77
	Block size (100 x 200 x 80 mm)	3	23.4	5.57
		4	25.5	3.65
W-retentive	JIS size (100 x 100 x 400 mm)	5	11.7	3.94
		6	13.8	3.63
	Block size (100 x 200 x 80 mm)	5	13.6	4.02
		6	15.9	3.32

1.2 Test results

1.2.1 Durability factor

The durability factor calculated from the results of the freeze-thaw resistance tests is shown in Table 3. Formula (1) was used to calculate the durability factor. While typical concrete mixes are considered to have sufficient freeze-thaw resistance if 60% or higher durability factor is achieved, the test results show that the durability factor is less than 60% for most cases, which is judged to be poor. The results also show that the durability factor is not correlated with either the air content or flexural strength.

$$DF = \frac{P \times N}{M} \quad \text{(1)}$$

DF: durability factor

P: relative dynamic modulus of elasticity at N cycles (%)

N: number of cycles at which P reaches 60% or M (300) cycles, whichever is less

M: 300 cycles

While site surveys have generally shown that no damage due to freeze-thaw effects has been caused in Japan with standard blocks (of which flexural strength is 5 N/mm^2 or higher) and permeable blocks (3 N/mm^2 or higher), the current test results do not confirm this. It may be the case that JIS A 1148 sets more stringent test conditions than those expected in the real environment, as freeze-thaw effects are applied from the entire outside surface to the inside of test pieces with the JIS A 1148 method, whereas freeze-thaw effects are expected to be applied only from one side with actual paving blocks in the field. Accordingly, when performing freeze-thaw resistance tests of concrete paving blocks, it is necessary to use a freeze-thaw mechanism and temperature conditions that are as close as possible to those of the real environment.

Table 3 Durability factor

Type, seize, method		No.	Air content (%)	Flexural strength (N/mm^2)	Durability factor (%)
Standard JIS size	A	1	1.5	6.06	12
		2	13.5	3.98	35
	B	1	1.5	6.06	37
		2	13.5	3.98	68
Standard Block size	A	1	2.5	7.29	10
		2	13.2	4.15	28
	B	1	2.5	7.29	27
		2	13.2	4.15	7
Permeable JIS size	A	3	23.6	3.35	6
		4	25.1	2.77	5
	B	3	23.6	3.35	40
		4	25.1	2.77	43
Permeable Block size	A	3	23.4	5.57	10
		4	25.5	3.65	26
	B	3	23.4	5.57	38
		4	25.5	3.65	17
W-retentive JIS size	A	5	11.7	3.94	4
		6	13.8	3.63	3
	B	5	11.7	3.94	5
		6	13.8	3.63	5
W-retentive Block size	A	5	13.6	4.02	6
		6	15.9	3.32	6
	B	5	13.6	4.02	4
		6	15.9	3.32	2

2. TEMPERATURE MEASUREMENT OF BLOCKS IN THE REAL ENVIRONMENT

2.1 Outline of measurement

In order to investigate the conditions that concrete paving blocks are expected to be exposed to in an actual environment, standard blocks, permeable blocks, and water-retentive blocks were installed in a site in Masumoto City, Nagano, which is a snowy, cold region where freeze-thaw effects are expected to be severe. The installation conditions are shown in Photos 1.

Inner temperatures of the top and bottom (both

10 mm inside from the surface) of concrete paving blocks were measured under various conditions as well as the air temperature at which the entire concrete block was frozen. In addition, two types of base courses, i.e., granular and concrete base courses, were used and the difference was examined. Figure 1 illustrates plan views and cross sections of the pavement structure indicating the measurement points.

Photo 1 Installation Conditions

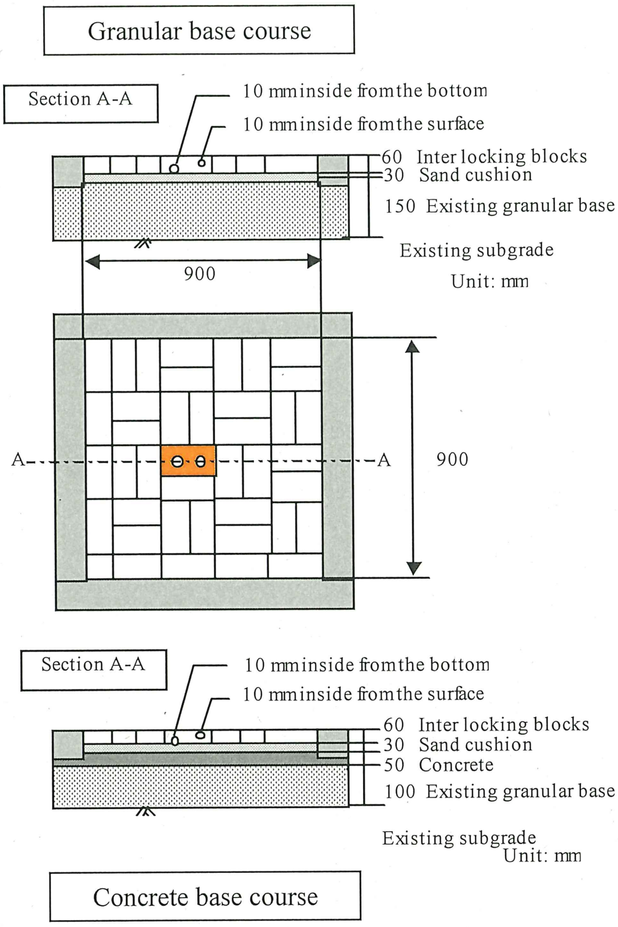

Figure 1 Plan view and cross section of measurement points

2.2 Measurement results

2.2.1 Example of measurement results

Example temperature measurement results are shown in Figure 2 and Figure 3, for the cases with and without snow accumulation on the paving blocks, respectively.

Without snow accumulation on the blocks, the temperature of the block changed with the air temperature and the range of temperature change was wider for the portion nearer to the surface. Also, it was found that freezing progresses downwards from the top of the block, regardless of the type of base course. This result was the same for paving blocks of different mix proportions.

With snow accumulation on the blocks, changes in air temperature had little effect on the block temperature, which was stable within a range of 0.5 – 2°C. This is believed to have been caused by the shielding effect of the snow layer, which works to isolate the blocks from air temperature and solar irradiation. This result was also the same for paving blocks of different mix proportions.

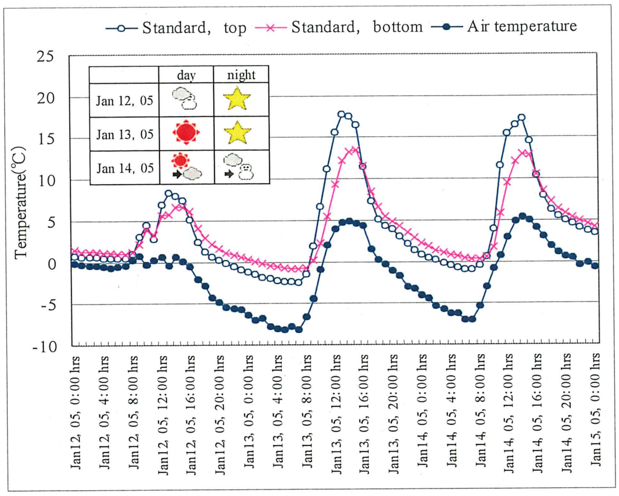

Figure 2 Example measurements (without snow accumulation)

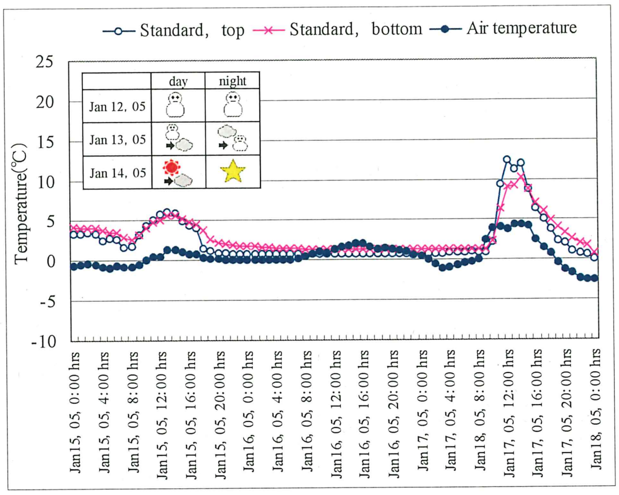

Figure 3 Example measurements (with snow accumulation)

2.2.2 Air temperature to freeze blocks

Table 4 shows the estimated air temperature at which the paving blocks would freeze down to the bottom, derived from the relationship between air temperature and block temperature for the case without accumulated snow.

The results indicate that the block freezing temperature depends on the type of block and that even the block type most resistant to freezing was frozen to the bottom at an air temperature of –8.0°C or below. Regarding the type of base course, it was found that the concrete base was more difficult to be frozen than the granular base. This is believed to be related to the moisture drawn into the block from the base course as well as the amount of evaporation from the block. As granular base courses can retain more moisture than concrete base courses, more moisture may be drawn into blocks from the base course and thus the condition of high water content would last for a longer period. On the contrary, concrete base courses will experience a shorter period of high water content compared to granular base courses. This is thought to be the reason why blocks on a concrete base are more resistant to freezing.

Among the measurement results, the lowest temperature that was sufficient to freeze the blocks down to the bottom was –8°C. It is therefore considered reasonable to use the lowest air temperature of –8°C as the condition to be applied to freeze-thaw tests of concrete blocks.

Table 4 Air temperature to freeze blocks (Matsumoto city)

		Block type	Temperature (°C)	
			Upper	Lower
No snow cover	Granular base course	Standard	-3.2	-4.7
		Permeable	-3.7	-4.7
		Water-retentive	-3.2	-4.5
	Concrete base course	Standard	-6.1	-7.6
		Permeable	-6.2	-8.0
		Water-retentive	-4.9	-7.4

3. STANDARDIZED FREEZE-THAW TESTS IN OTHER COUNTRIES

Table 5 lists the freeze-thaw test standards in other countries. [5] [6] [7] [8] [9]
Among them, two standards, ASTM C936-01-2004 and CSA Standard A231.2-95, were selected for the freeze-thaw tests.

Table 5 Summary of freeze-thaw test standards in other countries

Standard	ASTM C936-01-2004	JC/T446-2000	CSA Standard A231.2-95	EU Standard, UK, Austria	RILEM Test Method
Country	USA	China	Canada	EU, UK, Austria	
Standard (test method)	ASTM C67-02	JC/T446-2000	CSA Standard A231.2-95	EN 1338	RILEM (CDF-Test)
Freeze-thaw procedure	One side immersion for freezing and underwater thawing	Atmospheric freezing and underwater thawing	Underwater freezing and thawing	One side immersion for freezing, underwater thawing	One side immersion for freezing and thawing
Age of test piece	Within 12 months of delivery	28 days or more	28 days or more	20 days or more	7 days or more
Freezing/thawing media	Water	Water	NaCl solution, 3%	NaCl solution, 3%	NaCl solution, 3%
No. of test pieces	5	5	5	3	5 or more
Test piece shape	Actual product	Actual product	Actual product	Actual product (specified surface area)	Actual product (cut as necessary)
Freezing/thawing temp. range	–9 to +24°C	–15 to +20°C	–15 to +5°C	–20 to +24°C	–20 to +20°C
Temp. measured at	Inside the test equipment	Freezing: in the room Thawing: underwater	Inside the test equipment	Surface of the test piece	Freezing solution
Duration of one cycle	24 h	32 h	24 h	24 h	12 h
Test cycle	50 cycles or 3% mass loss	25 cycles (34 days)	Continue until 25 cycles unless the mass loss exceeds 200 g/m2. If the mass loss exceeds 200 g/m2, continue until 50 cycles.	23 cycles	28 cycles
Pass/fail criteria	Test paver fails if: (1) the mass loss is 1.0% or more, (2) it disintegrates, or (3) cracking becomes larger than the minimum size of the test piece.	(1) Determine if there is any surface spalling, scaling, or cracking. (2) Perform a compression or flexural strength test and check whether the strength is decreased by 20% from the initial strength. If it is less than 20%, the tested paver is judged satisfactory.	When tested according to the "Deicing Salt Freeze-Thaw Durability Test", the average loss of mass of three full-size pavers shall not be greater than: (a) 200 g/m^2 of the total surface area of the individual paver after 25 cycles of freezing and thawing; or (b) 500 g/m^2 of the total surface area of the individual paver after 50 cycles of freezing and thawing.	Upon completion of testing, the mass loss shall be determined by a square meter. If the mean value of the loss is 1 kg/m^2 or less and no mass loss of 1.5 kg/m^2 is measured, the tested pavers shall be classified as Class 3 (symbol D).	Upon completion of CDF testing, the mass loss shall be determined by a square meter. If the value is 1500 g/m^2, the tested paver is judged satisfactory.

4. FREEZE-THAW TESTS TO USE STANDARDS OF OTHER COUNTRIES

4.1 Overview of Tests

The same concrete mix proportions, filling factor, and flexural strength as those listed in Tables 1 and 2 were used and the block-size test pieces were used, as it is specified in these standards that actual products must be used.

Figure 4 and Figure 5 show cross-section views of the freeze-thaw test methods of ASTM C67-02a and CSA Standard A231.2-95, respectively.

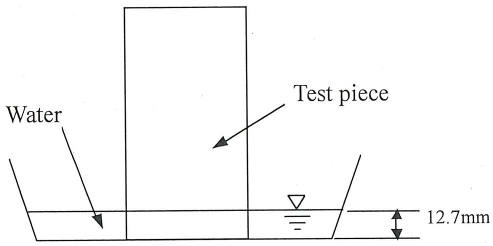

Figure 4 ASTM C67-02a Test Method

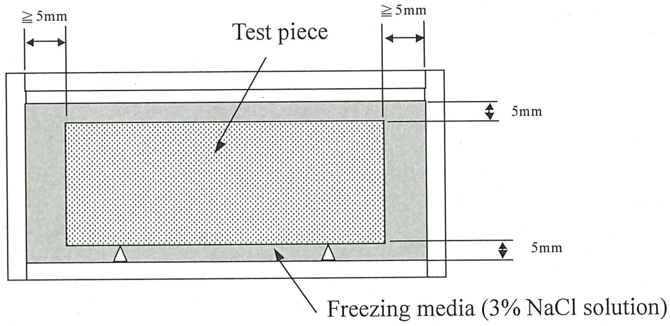

Figure 5 CSA Standard A231.2-95 Test Method

4.2 Test results

(1) ASTM C936-01-2004

Table 6 lists the freeze-thaw test results based on the ASTM C936-01-2004 method.

With the standard blocks, no mass loss was observed after 50 cycles of freeze-thaw tests with no cracks or breaks, thus satisfying the requirements of the standards. With the permeable blocks after 50 cycles of tests, while the requirements were met with no mass loss and no cracks or breaks for the mix proportion corresponding to the flexural strength of 5.57 N/mm^2, the mass loss exceeded 1% with the mix proportion of 3.65 N/mm^2 flexural strength. This is considered due to breaks observed in the moist part. With the water-retentive blocks, no mass loss was observed after 50 cycles of tests. However, while the requirements were met with no cracks or breaks for the mix proportion of 4.02 N/mm^2 flexural strength, cracks exceeding the minimum size of the test piece were observed with the mix proportion of 3.32 N/mm^2 flexural strength and thus failed to meet the requirements.

Table 6 Freeze-thaw test results (ASTM C936-01-2004)

Type	Air content (%)	Flexural strength (N/mm^2)	Mass loss after 50 cycles (%)	Cracking, chipping	Pass/fail criteria	Pass or fail
Standard	2.5	7.29	−2.06	NIL	Test paver fails if: (1) the mass loss is 1.0% or more, (2) it disintegrates, or (3) cracking becomes larger than the minimum size of the test piece.	Pass
	13.2	4.15	−0.89	NIL		Pass
Permeable	23.4	5.57	−0.61	NIL		Pass
	25.5	3.65	1.41	Chipping on the edge of the immersed side.		Fail
W-retentive	13.6	4.02	−0.94	NIL		Pass
	15.9	3.32	−0.77	Cracking larger than the minimum size of the test piece		Fail

(2) CSA Standard A231.2-95

Table 7 lists the freeze-thaw test results based on the CSA Standard A231.2-95.

Regarding the mass loss of test piece blocks, standard blocks and permeable blocks satisfied the specification limit of 200 g/m^3 or less after 25 cycles of tests even when the unit water content was changed. As water-retentive blocks failed to satisfy the mass loss specification limits at the end of 25 cycles, the test was extended to 50 cycles. However, the resulting mass loss significantly exceeded the 500 g/m^2 specification limit and so failed to comply with the standard. As water-retaining material is added to the mix proportion of water-retentive blocks to improve the water-absorbing and water retention properties, inclusion of such materials is believed to affect the freeze-thaw resistance.

Table 7 Freeze-thaw test results (CSA Standard A231.2-95)

Type	Air content (%)	Flexural strength (N/mm^2)	Mass loss (g/m^2)		Pass/fail criteria	Pass or fail
			25 cycles	50 cycles		
Standard	2.5	7.29	77.2	-	When tested according to the "Deicing Salt Freeze-Thaw Durability Test", the average loss of mass of three full-size pavers shall not be greater than: (a) 200 g/m^2 of the total surface area of the individual paver after 25 cycles of freezing and thawing; or (b) 500 g/m^2 of the total surface area of the individual paver after 50 cycles of freezing and thawing.	Pass
	13.2	4.15	32.0	-		Pass
Permeable	23.4	5.57	13.7	-		Pass
	25.5	3.65	14.0	-		Pass
W-retentive	13.6	4.02	208.1	7341		Fail
	15.9	3.32	213.6	10719.4		Fail

At present, there have been few tests in Japan, although the test results in the present study were obtained in freeze-thaw tests of concrete paving blocks based on ASTM and CSA standards. It is therefore important to accumulate test data by carrying out further similar tests.

5. CONCLUSION

Through this series of evaluation studies, the following conclusions were drawn. To establish a Japanese standard for the freeze-thaw test method for concrete paving blocks, further study of similar test methods in other countries is necessary.

(1) Although site surveys generally show that no damage due to freeze-thaw effects has been caused in Japan with standard blocks (of which flexural strength is 5 N/mm^2 or higher) and permeable blocks (3 N/mm^2 or higher), these concrete paving blocks were evaluated in accordance with JIS A 1148, resulting in a durability factor of less than 60%, and so the blocks are considered to have poor freeze-thaw resistance. This may be due to the fact that the test procedures do not accurately reproduce the actual freeze-thaw conditions in a real environment.

(2) The tests carried out in a snowy, cold region of Japan showed that concrete paving blocks can be fully frozen to the bottom at an air temperature as low as –8°C, so it is desirable to establish test methods accordingly.

(3) When concrete paving blocks are tested using ASTM C936-01-2004 and CSA Standard A231.2-95 test methods, different evaluation results on the freeze-thaw resistance are obtained from these two methods although the flexural strength is the same.

REFERENCE MATERIAL

1. Interlocking Block Pavement Engineering Design and Build Guidelines, July 2000, Japan Interlocking Block Pavement Engineering Association
2. JIS A 1148-2001 "Methods of testing for resistance of concrete to freezing and thawing"
3. JASS 7 M101 "Flexural strength test methods for interlocking blocks"
4. JIS A 1106 "Method of test for flexural strength of concrete"
5. ASTM C936-01-2004 "Standard Specification for Solid Concrete Interlocking Paving Units"
6. JC/T446-2000 "Precast Concrete Paving Units"
7. CSA Standard A231.2-95 "Precast Concrete Pavers"
8. EN 1338 Concrete paving blocks – Requirements and test methods
9. RILEM "Recommendation for Test Method for the Freeze-Thaw Resistance of Concrete Tests with Sodium Chloride Solution (CDF)"