

Influence that Ratio of Length to Diameter of High-Strength Concrete Core to Compressive Strength of Concrete

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ABSTRACT

It is necessary and very important to take concrete core from structures for researching the durability and strength of existing RC structures.

When taking core from concrete structures, sometimes the ratio of length to diameter [L/D] of cores for strength testing are shorter than 2.00.

If the L/D of the specimen is less than 2.00, the strength correction factor should be used to estimate the compressive strength of concrete cores.

The strength correction factor is provided for the concrete of normal compressive strength up to 40 N/mm² in JIS A 1107 or ASTM C42. Therefore, it is not applied to high-strength concrete.

As a result of the consideration for relationship between the L/D and the compressive strength of concrete cores that would be tested in accordance with JIS A 1107, it was confirmed that the strength correction factor listed on JIS A 1107 and ASTM C42 are valid for high-strength concrete up to 100 N/mm².

KEYWORDS

High-strength concrete, Concrete core, Ratio of length to diameter, Strength correction factor.

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1 INTRODUCTION

It is necessary and very important to take concrete core from structures for researching the durability and strength of existing RC structures.

When the service life of RC structures are presumed, the durability of concrete, for example, carbonation depth or the corrosion level of reinforcement in the concrete are measured.

For the verification of the progress level of the carbonation depth, the strength presumption by the strength test or non-destructive tests.

In addition, for last 30 years recently, the high-strength concrete has increased to use for RC structures, especially for the high rise buildings in the world. It also needs to execute an accurate strength estimation for the durability of building materials, when the seismic retrofit or repairing of RC structures in the future.

This research shows very important technical intelligence to execute an accurate strength estimation, when durability of existing concrete structure would be presumed.

To determine compressive strength of structural concrete, concrete core specimens are taken from structural members. Generally, compressive strength tests are carried out on core specimens of 100mm diameter and 200mm length.

However, in some cases, high-strength concrete structure members are thinner than specimen's length. It was because that the bar arrangement is different or sometimes drilling core specimens are accidentally sawed short with small length-to-diameter ratios. It would be resulting in high values of core concrete strength that do not reflect actual strength of structural concrete.

Because of such inversely proportional relationship between the compressive strength of short cores and their length-to-diameter ratios, the strength correction factor is recommended in standards JIS A 1107-2002 and ASTM C42-2004.

These correction factors are valid for cores of concrete strength under 40MPa [N/mm^2], so it does not applied to cores of higher strength concrete.

When the compressive strength of cores above 70MPa [N/mm^2] would be measured, the strength correction factor may become larger than listed on JIS A 1107 and ASTM C42. According to the experiments of Bartlett and MacGregor [1994], Tomosawa *et al.* [1989] and Pertersons [1971], when the compressive strength increased to high-strength concrete, the strength correction factor become larger than normal strength concrete.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Experimental Program

Based on compressive strength tests, this study estimates the strength correction factor would be applied for high-strength concrete cores, compressive strength up to 100 N/mm^2 .

Target compressive strengths were two normal strength concrete [30 and 45 N/mm^2] and three high strength concrete [60, 80 and 100 N/mm^2].

Concrete core specimens of 100mm and 75mm diameters were cut into different lengths with respect to the following length-to-diameter [L/D] ratios 1.00, 1.25, 1.50, 1.75 and 2.00.

Core specimens of 75mm diameter are suitable when structure member are thinner than 200mm or bar arrangement interval narrow than core diameter of 100mm.

Parameter and level of the compressive strength test for cores in this experimental study are showed in Table 1.

Table 1. Parameter and level of the compressive strength test for cores.

<i>Parameter</i>	<i>Level</i>
Target Compressive Strength [N/mm ²]	30, 45, 60, 80, 100
Ratio of length to diameter [L/D]	1.00, 1.25, 1.50, 1.75, 2.00
Diameters of core [mm]	φ 100, φ 75
Types of mock-up [Direction of drilling core to placing concrete]	Wall shape [vertical], Slab shape [horizontal]
Testing age [day]	28, 56

2.2 Materials and Mix Proportions

Concrete component materials and specifications are showed in Table 2.

Table 2. Concrete component materials and specifications.

<i>Concrete component materials</i>		<i>Specifications</i>
Cement	OPC	Conforming JIS R 5210, Specific gravity 3.16 g/cm ³
	MHPC	Conforming JIS R 5210, Specific gravity 3.21 g/cm ³
Fine aggregate	River sand	SSD specific gravity 2.61 g/cm ³ Absorption 1.16 %, F.M. 2.80
Coarse aggregate	Crushed stone	SSD specific gravity 2.70 g/cm ³ Absorption 0.75 %, Solid content 60.0 %
Admixture	Water reducing agent	Sodium Lignosulfonate, Specific gravity 1.07 g/cm ³
	Super plasticizer	Polycarboxylate, Specific gravity 1.07 g/cm ³

Ordinary Portland Cement [OPC] were used for the strength levels of 30, 45, 60 and 80 N/mm². Moderate Heat Portland Cement [MHPC] was used for the strength level of 100 N/mm².

River sand and crushed stone were used for the aggregate of all concretes.

Water reducing agent was used for the strength level of 30 N/mm² and super-plasticizer were used for the other strength levels.

Mix proportions of concrete are showed in Table 3.

For the strength levels of 30 and 45 N/mm², water to cement ratio were decided aiming to reach the target strength at age of 28 days of core specimens. For the strength levels of 60, 80 and 100 N/mm², these water to cement ratio were decided aiming to reach the target strength at age of 56 days.

Table 3. Strength level and mix proportions of concrete.

Strength level [N/mm ²]	Water to cement ratio [%]	Cement [kg/m ³]	Water [kg/m ³]	SSD fine aggregate [kg/m ³]	SSD coarse aggregate [kg/m ³]	Admixture [kg/m ³]	
						Water reducing agent	Super plasticizer
30	61.0	292	178	880	940	2.92	—
45	45.0	378	170	833	934	—	3.78
60	37.5	453	170	780	926	—	4.67
80	28.0	607	170	710	867	—	8.19
100	27.0	630	170	715	851	—	9.77

2.3 Wall and Slab Shape Mock-up

To prepare concrete core specimens of different length-to-diameter ratios, a wall shape mock-up was made for each strength level, and a slab shape mock-up was made for the strength levels of 30 and 60 N/mm².

Figure 1 shows the wall shape mock-up size and concrete core drilling locations.

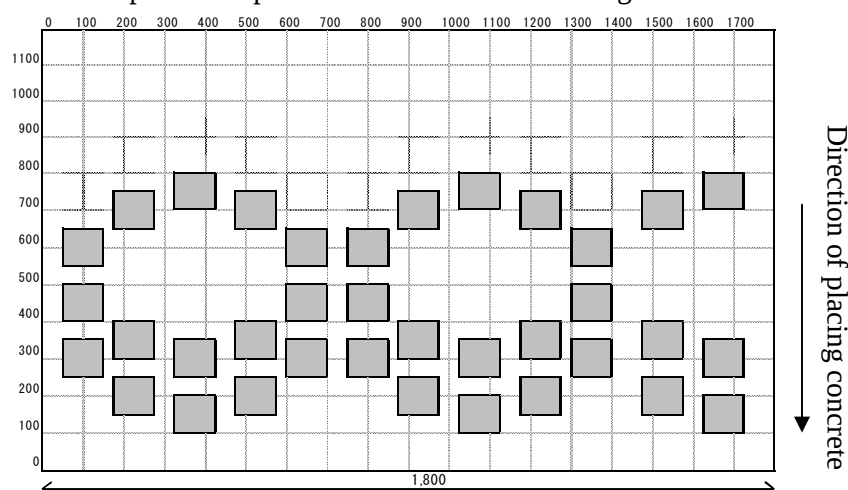


Figure 1. Wall shape mock-up size and core drilling locations [Dimensions in millimetres].

Two types of mock-up were made, which would be compared to compressive strength correction factor effecting of core drilling direction to placing concrete direction.

The wall shape mock-up was placing concrete into the plywood forms from the top of the mock-up. And then, when the drilling core from the mock-up, it was vertical angle to the wall shape mock-up. The other hands, the slab shape mock-up was placing concrete and drilling concrete, that would be same direction.

The mock up of wall shape was 1800mm width, 1200mm height and 325mm thickness and the mock up of slab shape was 1800mm×1200mm width and 325mm thickness.

After placing concrete into plywood forms, each mock-up were cured until the age of 14 days for the strength levels of 30, 45, 60 and 80 N/mm², and until 21days for the strength level of 100 N/mm².

For the strength levels of 30 and 45 N/mm², core specimens were drilled at the age of 21 days. For the strength levels of 60, 80 and 100 N/mm², core specimens were drilled at the age of 49 days.

After drilling, all core specimens were cured in water at job site until moving to the testing center.

2.4 Preparation of Core Specimens

Concrete cores were drilled from the mock-up 1 week before the compressive strength test. After drilling, concrete cores were sawed into lengths each of the following ratios, $L/D=1.00$, 1.25, 1.50, 1.75 and 2.00 and grounded on both ends.

Figure 2 shows specimen's lengths from concrete cores before sawed and grounded on both ends. 7 core specimens for every parameter were tested.

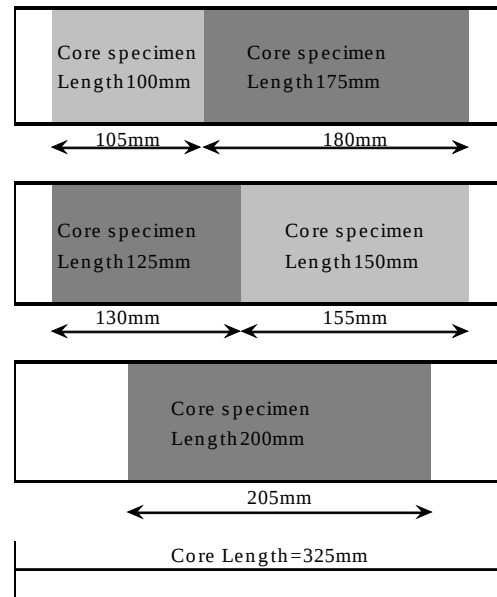


Figure 2. Specimen's length from concrete cores before sawed [e.g. Diameter of core : 100mm].

2.5 Compressive Strength Test

The compressive strength test was carried out in accordance with JIS A 1108 at one testing center that conformed ISO17025 laboratory. At the testing centre, specimens were cured in water at $20\pm1^{\circ}\text{C}$ until the compressive strength test.

For the strength levels of 30 and 45 N/mm^2 , core specimens were testing at the age of 28 days. For the strength levels of 60, 80 and 100 N/mm^2 , core specimens were testing at the age of 56 days. Testing days were decided by the measure of the compressive strength of the specimens making by mould with mock-up. The loading rate was kept at around 0.6 $\text{N/mm}^2/\text{sec}$ during the compressive strength test.

3 RESULTS AND DISCUSSION

3.1 Compressive Strength and Strength Correction Factor

The mean values of the compressive strength and the standard deviation of the core specimens which taking from wall shape mock-up are given in Table 4 and the core specimens taking from slab shape mock-up are given in Table 5. The standard deviation are denoted in parentheses.

The compressive strength increased as the length-to-diameter ratio decreased at any strength levels. The compressive strength ratio, which is the ratio of the compressive strength of each specimens to the compressive strength at $L/D=2.00$ of the same strength level, was estimated for each strength levels.

The compressive strength ratio of the core specimens taking from wall shape mock-up are given in Table 6 and the core specimens taking from slab shape mock-up are given in Table 7.

Table 4. Result of the mean values of the compressive strength and the standard deviation of core specimens taking from wall shape mock-up.

<i>L/D</i>	30 N/mm ²		45 N/mm ²		60 N/mm ²		80 N/mm ²		100 N/mm ²	
	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$
2.00	27.3 [1.66]	28.9 [1.51]	40.9 [3.89]	45.3 [1.08]	55.8 [1.25]	59.9 [2.71]	67.8 [1.84]	69.2 [1.84]	84.9 [2.74]	86.0 [2.82]
1.75	28.0 [1.15]	—	41.7 [2.80]	—	57.9 [1.76]	—	68.8 [3.06]	—	86.8 [2.54]	—
1.50	27.7 [1.36]	30.8 [2.10]	40.2 [5.05]	42.5 [2.97]	57.4 [2.24]	61.0 [6.53]	69.1 [2.79]	71.4 [2.74]	88.7 [1.78]	90.9 [2.70]
1.25	29.1 [1.93]	—	44.9 [3.34]	—	60.4 [5.20]	—	71.9 [3.00]	—	91.4 [3.80]	—
1.00	32.5 [1.27]	33.5 [3.18]	47.3 [2.74]	50.2 [3.64]	64.5 [3.52]	68.4 [4.32]	75.5 [3.08]	78.3 [1.98]	94.9 [4.11]	96.8 [5.73]

Table 5. Result of the mean values of the compressive strength and the standard deviation of core specimens taking from slab shape mock-up.

<i>L/D</i>	30 N/mm ²	60 N/mm ²
	$\phi 100$	$\phi 100$
2.00	30.6 [0.62]	54.5 [0.75]
1.50	30.8 [1.35]	54.2 [3.44]
1.00	33.9 [1.22]	59.8 [5.25]

Table 6. Result of compressive strength ratio of core specimens taking from wall shape mock-up.

<i>L/D</i>	30 N/mm ²		45 N/mm ²		60 N/mm ²		80 N/mm ²		100 N/mm ²	
	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$	$\phi 100$	$\phi 75$
2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.75	1.03	—	1.02	—	1.04	—	1.01	—	1.02	—
1.50	1.01	1.06	0.98	0.94	1.03	1.02	1.02	1.03	1.04	1.06
1.25	1.07	—	1.10	—	1.08	—	1.06	—	1.08	—
1.00	1.19	1.16	1.16	1.11	1.16	1.14	1.11	1.13	1.12	1.13

Table 7. Result of compressive strength ratio of core specimens taking from slab shape mock-up.

<i>L/D</i>	30 N/mm ²	60 N/mm ²
	$\phi 100$	$\phi 100$
2.00	1.00	1.00
1.50	1.01	0.99
1.00	1.11	1.10

The compressive strength ratio respective to length-to-diameter ratio and compared to the coefficient from the strength correction factor listed on JIS A 1107 and ASTM C 42 are shown in Fig. 3. The strength correction factor listed on JIS A 1107 and ASTM C 42 are same.

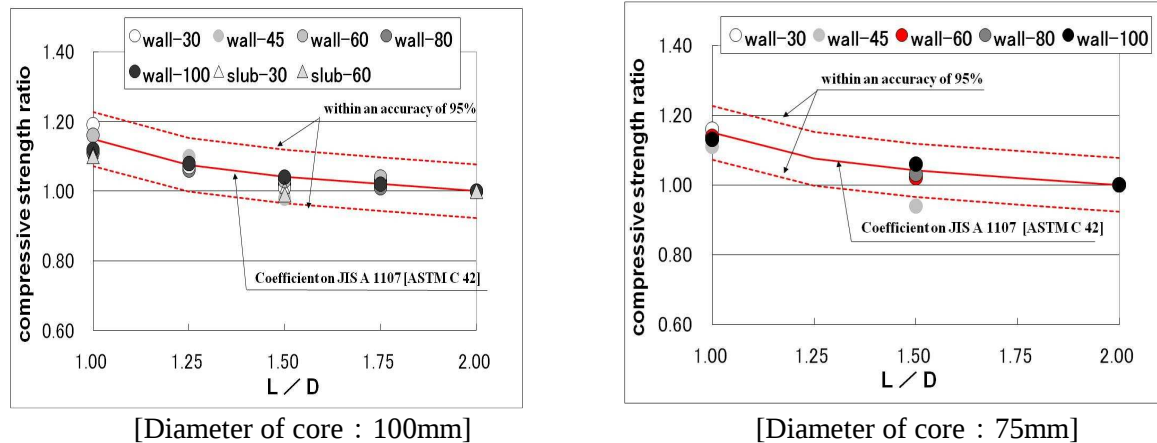


Figure 3. Compressive strength ratio respective to length-to-diameter ratio.

The compressive strength ratio increases as length-to-diameter ratio decreases, and it would be similar to the correction factor on JIS A 1107 at almost strength levels, diameters of core and types of mock-up, except one data of 45N/mm² level.

According to the experiments of Akaogi *et al.* [2008] and Kesler [1959], compressive strength ratio below 1.00 at the length-to-diameter ratio 1.50.

The compressive strength ratio at L/D=1.50 would be below 1.00, it is guessed that the test outcome was caused by some different mechanism to other L/D of the core specimens.

From this experimental compressive strength test results, the compressive strength ratio of any strength levels up to 100 N/mm² were within an accuracy of 95%.

Some data of high-strength concrete, which the compressive strength ratio at L/D=1.00 were above the correction factor on JIS A 1107 and ASTM C42. The data above the correction factor at L/D=1.00 would become an evaluation of the safety side. That means the strength correction factor listed on JIS A 1107 [ASTM C42] are valid for high-strength concrete up to 100 N/mm².

4 CONCLUSIONS

Based on compressive strength tests, this study estimates the strength correction factor of high-strength concrete cores of compressive strength in the range of 30 N/mm² to 100 N/mm².

Concrete core specimens were cut into different lengths with respect to the length-to-diameter ratios 1.00, 1.25, 1.50, 1.75 and 2.00.

The following results are drawn. Compressive strength ratio increases as length-to-diameter ratio decreases, and it would be similar to the correction factor on JIS A 1107 from the strength levels 30 to 100 N/mm².

The strength correction factor listed on JIS A 1107 and ASTM C42 are valid for high-strength concrete up to 100 N/mm².

Some case of length-to-diameter ratio at 1.50, the compressive strength ratio was below 1.00. It is guessed that the test outcome was caused by some different mechanism to other length-to-diameter ratio of the core specimens. It is planning to examine and research to clarify in the future.

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